U.S. CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD

INVESTIGATION REPORT

SUGAR DUST EXPLOSION AND FIRE

(14 Killed, 36 Injured)

IMPERIAL SUGAR COMPANY

PORT WENTWORTH, GEORGIA

FEBRUARY 7, 2008

KEY ISSUES:

- COMBUSTIBLE DUST HAZARD RECOGNITION
- MINIMIZING COMBUSTIBLE DUST ACCUMULATION IN THE WORKPLACE
- EQUIPMENT DESIGN AND MAINTENANCE

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Contents

Figures

Tables

Acronyms and Abbreviations

AIB	AIB International
ABA	American Bakers Association
ATF	U.S. Bureau of Alcohol, Tobacco, Firearms, and Explosives
CFR	Code of Federal Regulations
CSB	U.S. Chemical Safety and Hazard Investigation Board
EPA	U.S. Environmental Protection Agency
gm	grams
GMP	Good Manufacturing Practice (GMP)
IC	Incident Commander
IBC	International Building Code
ICC	International Code Council
IFC	International Fire Code
L	Liter
m	meters
m^3	cubic meter
MEC	minimum explosible concentration
MIE	minimum ignition energy
MIT	minimum ignition temperature
mJ	millijoules
MSDS	Material Safety Data Sheet(s)
NEP	National Emphasis Program
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
μm	microns (10^{-6} meters)

Executive Summary

On February 7, 2008, at about 7:15 p.m., a series of sugar dust explosions at the Imperial Sugar manufacturing facility in Port Wentworth, Georgia, resulted in 14 worker fatalities. Eight workers died at the scene and six others eventually succumbed to their injuries at the Joseph M. Still Burn Center in Augusta, Georgia. Thirty six workers were treated for serious burns and injuries—some caused permanent, life altering conditions. The explosions and subsequent fires destroyed the sugar packing buildings, palletizer room, and silos, and severely damaged the bulk train car loading area and parts of the sugar refining process areas.

The Imperial Sugar manufacturing facility housed a refinery that converts raw cane sugar into granulated sugar. A system of screw and belt conveyors, and bucket elevators transported granulated sugar from the refinery to three 105-foot tall sugar storage silos. It was then transported through conveyors and bucket elevators to specialty sugar processing areas and granulated sugar packaging machines. Sugar products were packaged in four-story packing buildings that surrounded the silos, or loaded into railcars and tanker trucks in the bulk sugar loading area.

The U.S. Chemical Safety and Hazard Investigation Board (CSB) determined that the first dust explosion initiated in the enclosed steel belt conveyor located below the sugar silos. The recently installed steel cover panels on the belt conveyor allowed explosive concentrations of sugar dust to accumulate inside the enclosure. An unknown source ignited the sugar dust, causing a violent explosion. The explosion lofted sugar dust that had accumulated on the floors and elevated horizontal surfaces, propagating more dust explosions through the buildings. Secondary dust explosions occurred throughout the packing buildings, parts of the refinery, and the bulk sugar loading buildings. The pressure waves from the explosions heaved thick concrete floors and collapsed brick walls, blocking stairwell and other exit routes. The resulting fires destroyed the packing buildings, silos, palletizer building and heavily damaged parts of the refinery and bulk sugar loading area.

The CSB investigation identified the following incident causes:

1. Sugar and cornstarch conveying equipment was not designed or maintained to minimize the release of sugar and sugar dust into the work area.
2. Inadequate housekeeping practices resulted in significant accumulations of combustible granulated and powdered sugar and combustible sugar dust on the floors and elevated surfaces throughout the packing buildings.
3. Airborne combustible sugar dust accumulated above the minimum explosible concentration inside the newly enclosed steel belt assembly under silos 1 and 2.
4. An overheated bearing in the steel belt conveyor most likely ignited a primary dust explosion.
5. The primary dust explosion inside the enclosed steel conveyor belt under silos 1 and 2 triggered massive secondary dust explosions and fires throughout the packing buildings.
6. The 14 fatalities were most likely the result of the secondary explosions and fires.
7. Imperial Sugar emergency evacuation plans were inadequate. Emergency notifications inside the refinery and packaging buildings were announced only to personnel using 2-way radios and cell phones. Many workers had to rely on face-to-face verbal alerts in the event of an emergency. Also, the company did not conduct emergency evacuation drills.

Subsequent to the Imperial Sugar incident, the Occupational Safety and Health Administration (OSHA) announced it intends to initiate rulemaking on a combustible dust standard. This was among several recommendations that the CSBs 2006 *Combustible Dust Study* made to address combustible dust workplace hazards in general industry.

Based on this incident, the CSB makes recommendations to The Imperial Sugar Company; AIB International; The American Bakers Association; The Risk Management Society, Inc.; Zurich Services Corporation; and The Occupational Safety and Health Administration.

1.0 Introduction

1.1 Background

At about 7:15 p.m. on February 7, 2008, a sugar dust explosion occurred in the enclosed steel conveyor belt under the granulated sugar storage silos at the Imperial Sugar Company sugar manufacturing facility in Port Wentworth, Georgia. Seconds later, massive secondary dust explosions propagated throughout the entire granulated and powdered sugar packing buildings, bulk sugar loading buildings, and parts of the raw sugar refinery. Three-inch thick concrete floors heaved and buckled from the explosive force of the secondary dust explosions as they moved through the four-story building on the south and east sides of the silos. The wooden plank roof on the palletizer building was shattered and blown into the bulk sugar railcar loading area. Security cameras located at businesses to the north, south, and west of the facility captured the sudden, violent fireball eruptions out of the penthouse[1] on top of the silos, the west bucket elevator structure, and surrounding buildings.

When Garden City and Port Wentworth fire department personnel arrived minutes later they were confronted with dense smoke, intense heat, ruptured fire water mains, and large amounts of debris strewn around the fully involved burning buildings. Workers at the facility had already started search and rescue efforts and injured workers were being triaged at the main gate guardhouse.

Eight workers died at the scene, including four who were trapped by falling debris and collapsing floors. Two of these fatally injured workers had reportedly reentered the building to attempt to rescue their co-workers, but failed to safely escape. Nineteen of the 36 workers transported to Savannah Memorial Hospital who were severely burned were transported to the Joseph M. Still Burn Center in

[1] The silo penthouse was a weather-tight structure on top of the three silos that housed granulated sugar belt conveyors.

Augusta, Georgia where six eventually succumbed to injuries, bringing the total fatalities to 14 workers—the last burn victim died at the burn center six months after the incident.

Thirty six injured workers ultimately survived including some with permanent, life altering conditions. Approximately 85 other workers at the facility at the time of the incident were uninjured.

The major fires in the buildings were extinguished the next day, but small fires continued burning for many days. The granulated sugar fires in the 105-foot tall silos continued to smolder for more than 7 days before being extinguished by a commercial industrial firefighting company. The packing buildings, granulated sugar silos, and palletizer room were destroyed. The bulk sugar loading area and parts of the refinery were severely damaged by the explosion and fires (Figure 1).

Figure 1. West bucket elevator tower; silos 3, 2, and 1; and south packing building destroyed by the February 7, 2008, sugar dust explosions and fires

This report makes recommendations to Imperial Sugar Company; AIB International; the American Bakers Association; the Risk Insurance Management Society, Inc.; Zurich Services Corporation; and The Occupational Safety and Health Administration.

1.2 Investigative Process

The CSB investigation team arrived at the Imperial Sugar facility the morning of February 8, 2008. The Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF), the Georgia State Fire Marshal's office, and the responding fire departments were conducting victim recovery operations, fire suppression inside the silos and other hot-spots inside the buildings, and the cause and origin investigation.

The CSB team met with the Port Wentworth fire chief,[2] the ATF lead investigator, the State Fire Marshal, Occupational Safety and Health Administration (OSHA) investigators, and Imperial Sugar management personnel to explain the CSBs purpose and authority for conducting an investigation independently of the other agencies and organizations. The CSB and OSHA investigation supervisors coordinated witness interviews, evidence collection, and other investigation activities with the ATF lead investigator and the incident commander.

During the next 4 months, the CSB investigators examined and photographed the interior of the heavily damaged buildings and equipment and interviewed eyewitnesses who were working at the refinery the night of the incident, other company and contractor employees, and injured workers. The team examined engineering documents, worker training records, and equipment operation and maintenance records; witnessed the building demolition work; and examined equipment recovered from the wreckage before releasing the equipment to the company. Finally, the CSB commissioned

[2] Incident management conformed to the National Incident Management System (NIMS) structure throughout the fire suppression, search, rescue, and recovery activities. The Port Wentworth Fire Department headed the incident command.

testing to determine the combustibility characteristics of the granulated and powdered sugar, raw sugar, and cornstarch samples collected at the site.

1.3 Imperial Sugar Company

Imperial Sugar Company, headquartered in Sugar Land, Texas, was incorporated in 1924. The company purchased the Port Wentworth facility from Savannah Foods and Industries, Inc. in December 1997. At the time of the incident, Imperial Sugar operated the Port Wentworth facility and a sugar manufacturing and packaging facility in Gramercy, Louisiana, and a warehousing operation in Ludlow, KY. The sugar manufacturing facilities received raw sugar[3] and refined it into granulated sugar. Some granulated sugar was used to make powdered sugar, specialty sugars, and liquid sugar products. They packaged sugar products in capacities ranging from bulk tank and hopper railcar, to 100-pound bags, to small boxes and bags. Customers included industrial bakeries, and large chain and small grocers.[4] In 2007, the company produced more than 1.3 million tons of sugar, making it one of the largest sugar refiners in the U.S. More than 350 employees and contractors worked at the Port Wentworth facility, where annual sugar production exceeded 700 thousand tons.

1.3.1 Corporate Governance

Imperial Sugar Company is a public company, listed on the NASDAQ. The Imperial Sugar Company Board of Directors comprises eight members plus the board chairman. Board member backgrounds include investment banking, international diversified manufacturing, food and chemical manufacturing industries, and wholesale food distribution. The president and chief executive officer (CEO) is also a board member.

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[3] Imperial Sugar material suppliers process sugar cane into "raw sugar," a crystalline product that resembles light- to medium-brown granulated sugar. Raw sugar has low combustibility characteristics and is unlikely to generate combustible sugar dust.

[4] As of the date of this report, the Gramercy, LA facility continued operations and the Port Wentworth, GA facility was being rebuilt.

1.3.2 Corporate and Facility Management

Nine company officers in Sugar Land, Texas, manage the day-to-day business of Imperial Sugar. Management positions include finance, commodities management, general counsel, administration, engineering, technology, and sales (Figure 2). Prior to the incident, the company did not have a dedicated officer level position responsible for workplace safety. Instead, the corporate safety director reported to the director of human resources in the administration department. The director of human resources had minimal occupational safety management experience and training.

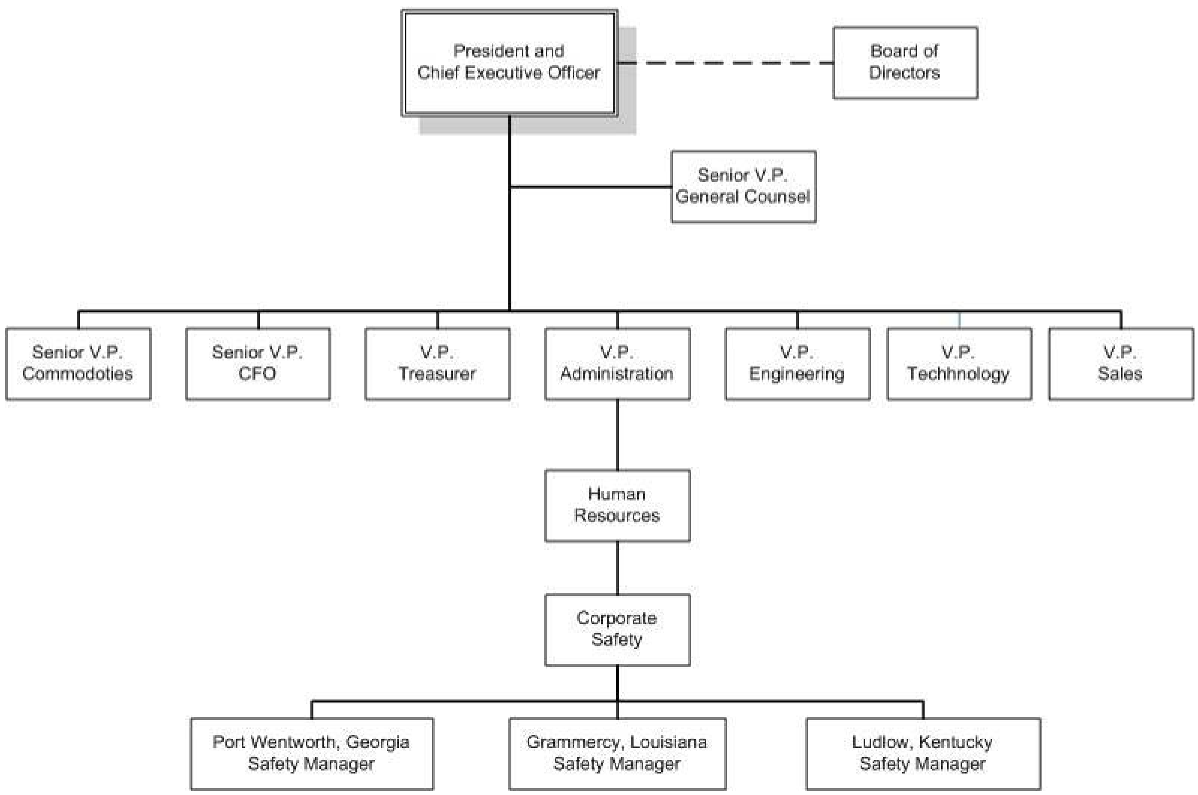

Figure 2. Imperial Sugar Company organization prior to the incident

The corporate safety director was responsible for overseeing workplace safety and facility security programs. The Port Wentworth management team had a safety and environmental manager who reported directly to the plant manager (Figure 3). Safety and product quality personnel at the refineries reported to the corporate technical services manager in Port Wentworth. The Port Wentworth safety coordinator reported to the safety and environmental manager.

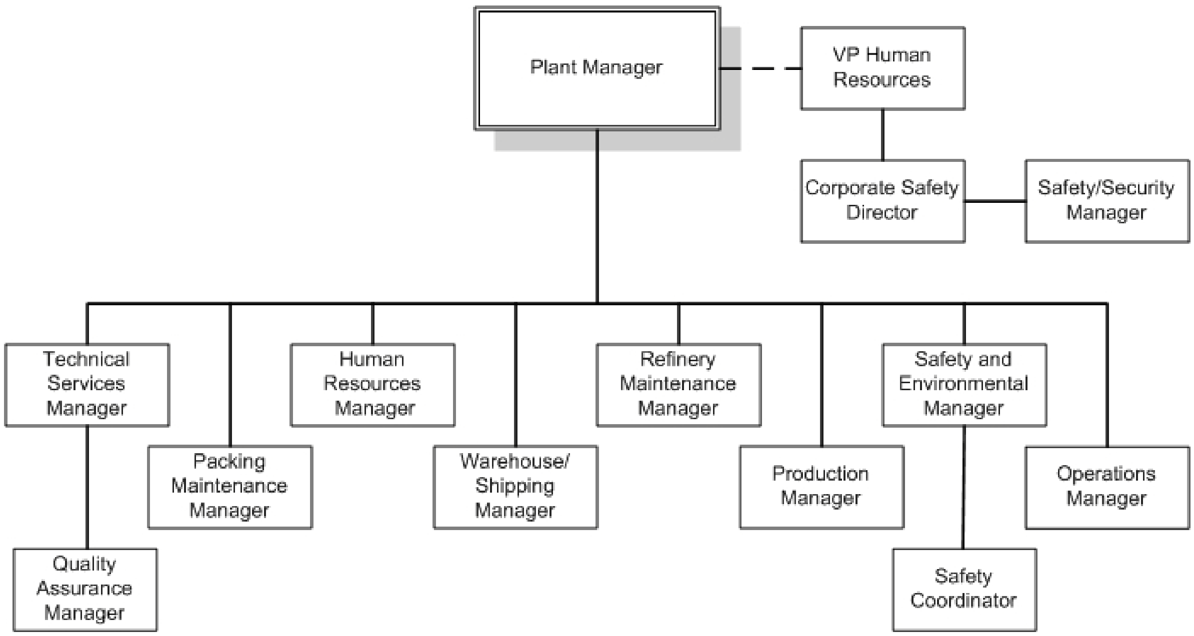

Figure 3. Port Wentworth, Georgia, organization prior to the incident

1.4 Facility Description

Savannah Foods and Industries, Inc. began constructing the Port Wentworth facility in the early 1900s; granulated sugar production started in 1917.[5] Over the years the facility added refining and packaging capacity, raw sugar and product warehouses, and upgraded the steam/electric powerplant (Figure 4).

Refined sugar was stored in three silos, and then transferred to the bulk sugar truck and train loading area, to the packing buildings, and to the powdered sugar production equipment, which was located in

[5] The product name "Dixie Crystals"® was created when the Savannah Foods refinery began production in the early 1900s.

the south packing building. Packaged products were palletized, and transferred to a warehouse for distribution to customers.

Figure 4. Imperial Sugar facility before the explosion. Granulated sugar storage silos and packing buildings are circled. Raw sugar warehouses in lower right (Chatham County, GA GIS photo)

Dozens of screw conveyors,[6] bucket elevators,[7] and horizontal conveyor belts transported granulated sugar throughout the packing buildings (Figure 5). Although bucket elevators were enclosed and screw conveyors were covered, they were not adequately sealed to prevent releasing sugar dust and sugar into the work areas. Because the large open work areas were not equipped with airborne dust removal equipment, sugar dust accumulated on overhead conduit, piping, ceiling beams, lights, and equipment. The closed granulated sugar screw conveyors located throughout the facility were not

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[6] A screw conveyor is a dry bulk material conveyor consisting of a rotating helical screw inside a closed trough. Granulated or powdered sugar enters the top feed opening at one end. The rotating helical screw pushes the sugar along the trough to the opposite end of the conveyor where it exits through a bottom discharge chute at the opposite end.

[7] A bucket elevator is a dry bulk material conveyor consisting of plastic or metal buckets attached to an endless fiber belt inside a closed vertical rectangular housing. Granulated sugar is scooped from a pit, or directly flows into the buckets at the base of the bucket elevator and pours out of the bucket into a discharge chute at the top of the housing.

equipped with dust removal equipment and were not designed to safely vent overpressure outside the building if combustible dust inside the enclosure ignited.

1.4.1 Granulated Sugar Storage Silos

Three 40-foot diameter, 105-foot tall concrete silos conditioned and stored the granulated sugar produced in the refinery. Each 5-million pound capacity silo sat on a raised circular concrete foundation above the packing building floor. Two belt conveyors were located under the silo floors in a 130-foot long tunnel, which was 7 ½ feet tall and 12 feet wide (Figure 6).

Granulated sugar from the refinery entered silo 3 and then was transferred into silo 1 and 2. The sugar was transferred from silos 1 and 2 to the bulk sugar building, powdered sugar mills, specialty sugar production equipment, and granulated sugar packing machines.

Sugar exited silo 3 into an Aerobelt® [8] conveyor in the silo tunnel, which discharged the sugar into the west bucket elevator pit. The bucket elevator lifted the sugar to the penthouse and onto another series of conveyor belts, into silos 1 and 2 (Figure 7 and Figure 8). Granulated sugar exited two 18-inch diameter penetrations in the floors of silo 1 and 2 onto a steel conveyor belt in the silo tunnel. Separate 18-inch diameter floor openings fed sugar to the screw conveyors under the north and south quadrants of each silo. Various conveyors and bucket elevators distributed the sugar to the powdered sugar mills, the packaging equipment, and the bulk sugar building.[9]

[8] An Aerobelt is a dust-tight conveyor belt assembly with a fiber belt that travels on an air cushion. It is equipped with dust collector attachment ports for removing airborne dust inside the enclosure, which were connected to the wet dust collectors.

[9] Granulated sugar was loaded into semi-trailers and railcars in the bulk sugar building.

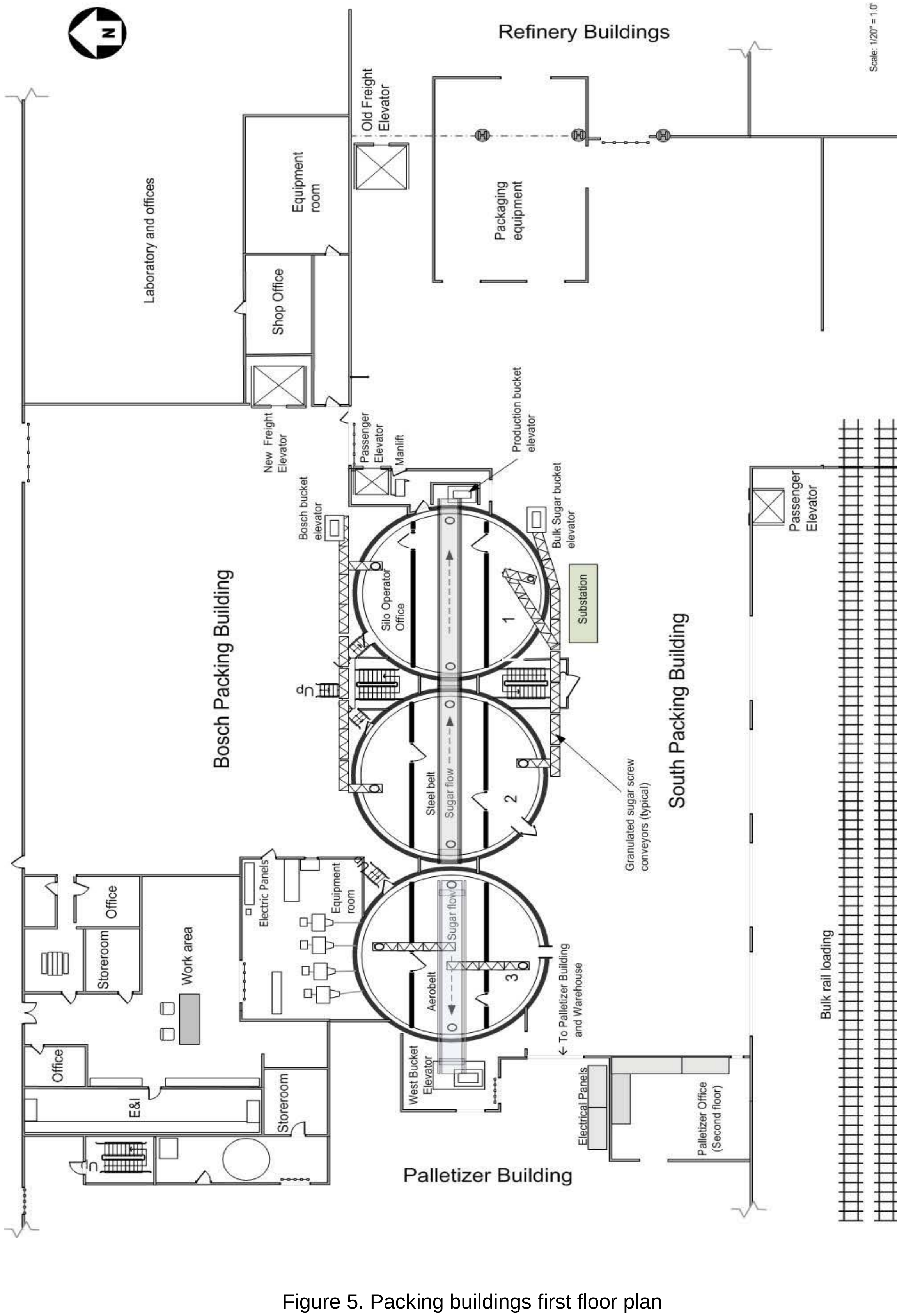

Figure 5. Packing buildings first floor plan

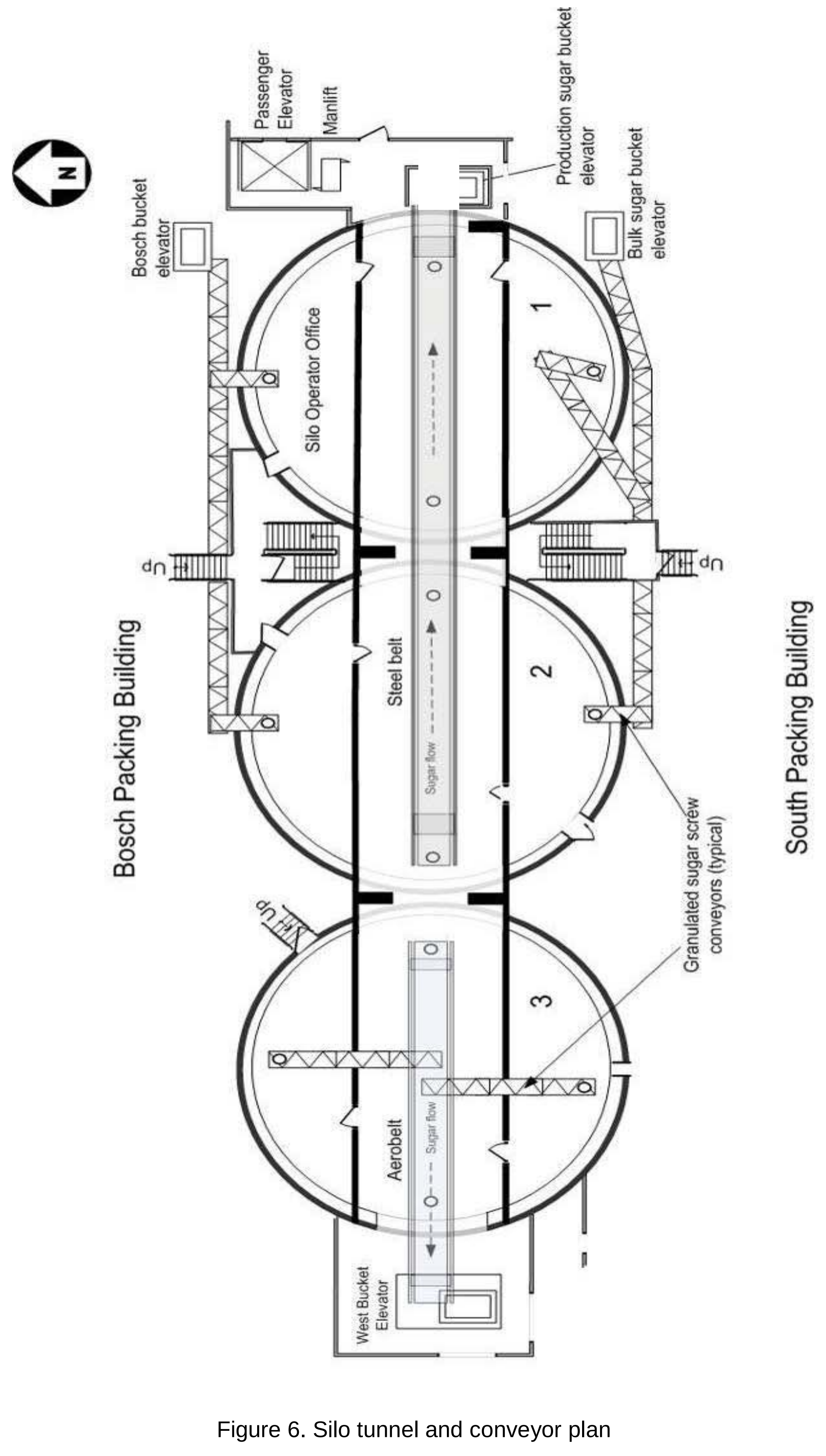

Figure 6. Silo tunnel and conveyor plan

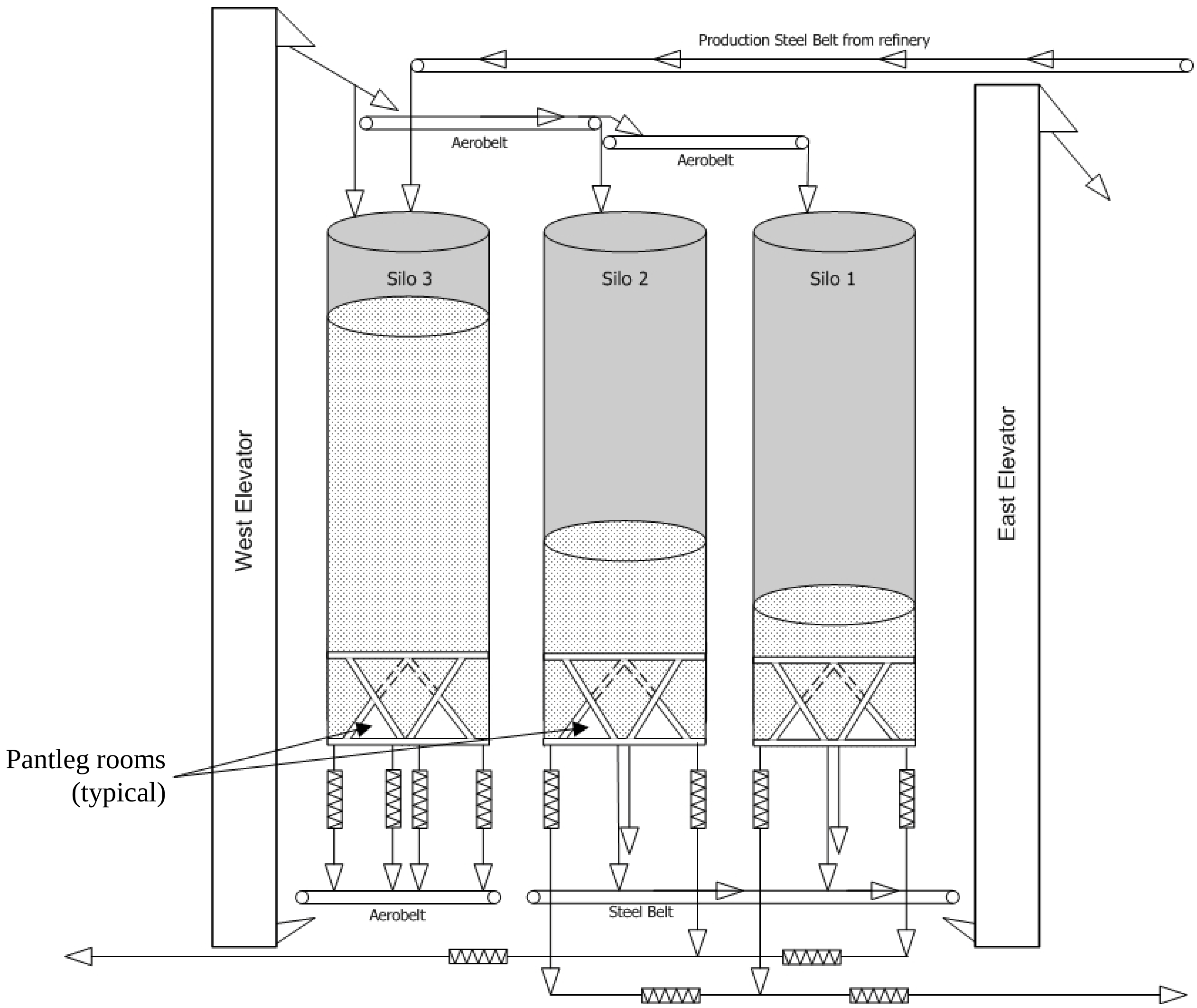

Figure 7. Granulated sugar supply and discharge through the silos

Figure 8. Granulated sugar steel conveyor belts above the silos, circa 1990. Heavy dust accumulation on conduit and spilled sugar on the floor (Imperial Sugar photo)

1.4.2 Silos 1 and 2 Steel Conveyor Belt

A 32-inch wide, 80-foot long steel conveyor belt (Figure 9) in the silo tunnel transported granulated sugar from silos 1 and 2 into the packaging production bucket elevator pit at the east side of silo 1. Similar steel belt conveyors were located in the penthouse above the silos.

Figure 9. Silo tunnel steel conveyor belt (removed after incident)

For many years, granulated sugar on these conveyors was exposed to possible contamination from debris that could fall onto the sugar. In 2007, Imperial Sugar installed a stainless steel frame with top and side panels to fully enclose each belt assembly to protect the granulated sugar from falling debris and reduce the possibility of intentional contamination. The top and side panels were removable to provide access for cleaning and conveyor maintenance. Although sugar dust was generated as the sugar flowed onto the belt and when flow blockages caused sugar to spill off the belt, these new enclosures were not equipped with a dust removal system and were not equipped with explosion vents.

During more than 80 years of operation, sugar dust released inside the large open volume of the silo tunnel most likely never accumulated to concentrations above the minimum explosible concentration (MEC). However, after the steel belt was enclosed, sugar dust was contained and remained suspended inside the unventilated enclosed space. Because the enclosure was one-tenth the volume of the tunnel,[10] sugar dust could easily accumulate to concentrations above the MEC. Furthermore, multiple potential dust ignition sources were identified inside the enclosure.

1.4.3 Bosch Packing Building

The four-story Bosch packing building located on the north side of the silos was a steel frame, corrugated steel-sided structure with poured concrete floors. Large doorways at the south-east corner on each floor gave forklift and personnel access to the south packing building. A steel-framed stairway enclosed in a concrete masonry block wall was located between silos 1 and 2 to provide access to each floor and the roof (see Figure 5).

Granulated sugar was transported by screw conveyors and a bucket elevator to the screens inside the "hummer room"[11] located on the roof of the building. Screw conveyors transported the screened sugar to feed hoppers on the third floor above each packaging machine. The second floor contained

[10] The volume inside the tunnel was approximately 8,700 cubic feet. The volume inside the enclosed steel belt assembly was approximately 850 cubic feet.

[11] The hummer room contained granulated sugar sieves, which removed lumps and separated the sugar into standard grain sizes.

granulated sugar packaging machines and paper and plastic packaging supplies. Conveyors transported the packaged sugar west to the palletizer room. Packaging supplies, including paper and plastic rolls, and pre-formed paper bags and boxes were stored on the first, third, and fourth floors.

1.4.4 South Packing Building

The south packing building was a four-story, steel-frame structure with 3-inch thick poured concrete floors and brick exterior walls. The three silos formed the north wall. A steel-frame, brick wall enclosed stairway was located between silos 1 and 2 to provide access to the floors above. The east end of the packing building opened into the refinery areas. Heavy, semi-transparent plastic strip curtains were typically installed on the large passageways to contain airborne dust.

The second and third floors housed granulated, powdered, and soft (brown) sugar packaging equipment. Screw conveyors and bucket elevators transported the granulated sugar to hoppers above the packaging equipment throughout the packing building. Belt and roller conveyors transported the packaged sugar products to the palletizer room, some passing through large openings in the floors and west wall.[12]

Container packaging supplies including paper, plastic, and cardboard were stored near the packaging equipment. Packaging machines filled paper and plastic bags and cardboard containers. The machines were equipped with Plexiglas® panels to protect workers from moving machine parts, hot surfaces, and other hazards. The enclosures also contained some of the sugar dust that was generated during container filling. Vacuum ductwork attached to the packaging machines removed some sugar dust from the packaging machines. Dust collectors located on the packing building roof removed sugar dust from air transferred from the packaging machines.

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[12] Floor and wall openings provided conduits for the explosive overpressures and fires.

The powdered sugar production equipment was located on the fourth floor. Cornstarch was transported from an outdoor storage silo into hoppers above the grinding mills through a pressurized air transfer line. A small amount of cornstarch[13] was added to the granulated sugar; then the mixture was fed into the grinding mills. The mills pulverized the granulated sugar/cornstarch mixture to the specified grain size, and then discharged the powdered sugar into hoppers above the packaging machines. The grinding mills were connected to the dry dust collectors system to remove airborne sugar and cornstarch dust.

1.4.5 Sugar Spillage and Dust Control

The CSBs investigation determined that sugar conveying and processing equipment were not adequately sealed; so significant quantities of sugar spilled onto the floors. Injury incident reports, internal correspondence, and other records identified significant accumulations of spilled sugar. Less than 2 months before the incident, an internal inspection performed by company supervisors and quality assurance personnel indicated that many tons of spilled sugar had to be routinely removed from the floors and returned to the refinery for reprocessing. Packaging operators and other employees also reported significant sugar dust escaping the packaging equipment into the work areas.

The cornstarch transport system, grinding mills, and powdered sugar packaging machines generated significant sugar dust in the work area. Workers reported that airborne sugar dust and spilled sugar in the powdered sugar processing and packaging work areas were a constant problem and that significant accumulations were typically seen on equipment and the floor. One worker told the CSB that he used a squeegee to clear a path on the floor through spilled powdered sugar to get to equipment he operated during his shift.

[13] Powdered sugar contains about 3% cornstarch to prevent the sugar from clumping.

Dust collection systems were attached to the packaging machines to remove sugar dust generated during container filling. Sugar screening equipment and the powdered sugar mills were also equipped with dust removal systems.

The dust transport ducts attached to the powdered sugar and cornstarch systems were connected to dry dust collectors. Dust transport ducts attached to granulated sugar equipment were connected to wet dust collectors. However, as reported in a January 2008 review of the dust handling system,[14] the dust collection equipment was in disrepair, and some equipment was significantly undersized or incorrectly installed. Some dust duct pipes were found to be partially, and in some locations, completely filled with sugar dust.

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[14] Imperial Sugar hired an outside consultant to evaluate air flow velocities, pressure drops, and other operating parameters on the dry and wet dust collection systems. The report identified numerous dust collection system design and maintenance deficiencies. Because the report was delivered only a few days before the February incident, Imperial Sugar management had not had the opportunity to review or act on the report findings.

2.0 Incident Description

2.1 Explosions and fires

Shortly before 7:15 p.m. on February 7, 2008, the new Imperial Sugar Company CEO[15] was touring the facility with three employees. Walking through the refinery toward the south packing building they were startled by what sounded and felt like a heavy roll of packing material dropped from a forklift somewhere in the packing building. Three to five seconds later a loud explosion knocked them backward, and debris was thrown through the large packing building doorway. The security guard at the gatehouse, and other workers in nearby buildings, also heard a loud explosive report. Outside, massive flames and debris erupted above the packing buildings and silos. A security camera at the Georgia Ports Authority located south of the facility recorded the first of many fireballs erupting from the Imperial Sugar facility (Figure 10).

Figure 10. Violent fireball erupting from the facility (elapsed time - 16 seconds) (Georgia Ports Authority security video).

Three-inch thick concrete floors in the south packing building heaved and buckled from the explosive force of the sugar dust-fueled explosions as they progressed through the packing buildings and into

[15] Imperial Sugar Company hired a new Chief Operating Officer in February, 2007. He was promoted to the position of Chief Executive Officer on January 29, 2008, nine days before the Port Wentworth explosion.

adjacent buildings. The wooden roof on the palletizer room was shattered and blown into the bulk sugar rail loading area.

Workers in the packing buildings had little or no warning as walls, equipment, and furniture were thrown about. Superheated air burned exposed flesh. Workers attempting to escape struggled to find their way out of the smoke-filled, darkened work areas. Debris littered the passageways. Some exits were blocked by collapsed brick walls and other debris. The fire sprinkler system failed because the explosions ruptured the water pipes.

Intense fireballs advanced through the entire north and south packing and palletizer buildings as sugar dust, shaken loose from overhead surfaces, ignited. Heaving and buckling floors opened large crevasses. The piles of granulated and powdered sugar that had accumulated around equipment rained down and intensified the fires burning below. Fireballs advanced through enclosed screw conveyors and ignited fires in the refinery and bulk sugar building hundreds of feet from the packing buildings where the incident had begun. Violent fireballs erupted from the facility for more than 15 minutes as spilled sugar and accumulated sugar dust continued fueling the fires (Figure 11).

Figure 11. Large fireball and burning debris erupt from the packing buildings 15 minutes after first explosion (elapsed time - 10 seconds) (PCS Phosphate security video).

2.2 Emergency Response

Garden City and Port Wentworth fire department personnel were on the scene in less than 10 minutes after the first explosion. They were confronted with dense smoke, intense heat, ruptured water mains, and large debris strewn around the fully involved burning buildings. The emergency responders immediately started search and rescue operation, which continued for many hours. Workers at the facility had already started search and rescue efforts, and seriously burned victims were being triaged at the main guardhouse north of the packing building and at the truck scale located west of the warehouse. Other agencies responded and assisted the Port Wentworth fire department with the emergency response, including

- Pooler, Bloomingdale, Thunderbolt, Savannah, and Effingham County Fire Departments
- Savannah Chatham Metropolitan Police
- Georgia State Fire Marshal
- Georgia Emergency Management Agency
- Chatham County Emergency Management Agency
- Georgia Search and Rescue
- Salvation Army
- American Red Cross

The major fires in the buildings were extinguished the next day; however, the silo fires continued to smolder for 7 days before they were finally extinguished on February 15.

Twelve Imperial Sugar employees and two contractors were fatally injured; four workers were fatally burned when falling debris and collapsing floors trapped them in the burning buildings. Four other workers could not escape the fires and died at the scene, including two who had reentered the burning structure to attempt to rescue their coworkers. Six seriously burned victims died at the Joseph M. Still Burn Center in Augusta, Georgia; the last died six months after the incident. Thirty-six injured workers, some seriously burned, ultimately survived. Approximately 70 other workers at the facility the night of the incident were uninjured.

3.0 Incident Analysis

3.1 Combustible Dust Characteristics

Combustible dust hazard studies, including sugar dust, date back more than 80 years. In 1924, R.V. Wheeler (Wheeler, 1924) divided combustible dusts into three classes based on ignitability and relative burn rates:

- Class I – Dusts that ignite and propagate flame readily, the source of heat required for ignition being comparatively small.
- Class II – Dusts that are readily ignited, and which, for the propagation of flame, require a heat source of large size or high temperature.
- Class III – Dusts that do not appear to be capable of propagating flame.

The 1925 publication *The Dust Hazard in Industry* (Gibbs) concludes that

> [S]ugar, dextrin, starch and cocoa are the most dangerous, sugar exceptionally so. Sugar ignites when projected as a cloud against a surface heated to below red heat, and when ignition has taken place, the flame travels throughout the dust-cloud with great rapidity.

The National Fire Protection Association (NFPA) defines a combustible dust as any "finely divided solid material regardless of particle size and [that] presents a fire or explosion hazard when dispersed and ignited in air" (NFPA, 2006). Standardized test procedures used to experimentally determine important properties of a combustible dust are listed in Table 1.

Table 1. Measured properties of combustible dusts (Dastidar, 2005)

Property	**Definition**	**Test Method**	**Application**
K_{st}	Dust deflagration index	ASTM E 1226	Measures the relative explosion severity compared to other dusts
P_{max}	Maximum explosion overpressure generated in the test chamber	ASTM E 1226	Used to design enclosures and predict the severity of the consequence
$(dP/dt)_{max}$	Maximum rate of pressure rise	ASTM E 1226	Predicts the violence of an explosion; used to calculate K_{St}
MIE	Minimum ignition energy	ASTM E 2019	Predicts the ease and likelihood of ignition of a dispersed dust cloud
MEC	Minimum explosible concentration	ASTM E 1515	Measures the minimum amount of dust, dispersed in air, required to spread an explosion. Analogous to the lower flammability limit (LFL) for gas/air mixtures

Table 2 lists particle sizes of common materials, and the sugar and cornstarch samples collected at the Port Wentworth facility.

Table 2. Particle size of some common combustible and non-combustible materials[16]

Material	Size (microns)
Talcum powder, red blood cells fine silt, cocoa	5 to 10
Pollen, milled flour, coarse silt	44 to 74
Table salt	105 to 149
Cornstarch from the Port Wentworth facility storage silo	10
Powdered sugar product from the Port Wentworth facility	23
Granulated sugar product from the Port Wentworth facility[1]	286

Note 1. Sample first passed through 500 µm sieve

The deflagration index, K_{st}, is used to estimate the relative explosion severity of the dust being examined. To determine K_{st}, dust samples of known particle size, moisture content, and concentration are ignited in a standard 20-liter test apparatus. The test chamber pressure as a function of time is recorded for successively increasing sample concentrations. The value of K_{st} is calculated using the equation:

$$K_{st} = (dP/dt)_{max} \text{ x } [\text{Test chamber volume}]^{1/3}$$

The higher the value of K_{st}, the more energetic a dust explosion can be. Combustible dust is assigned one of three hazard classes, ST1, ST2, or ST3, based on the deflagration index determined from the test results (Table 3).

[16] Source unless noted in table: http://www.wateruse.com/micron_equivalents.htm (June, 2009).

Table 3. Combustible dust hazard classes

Hazard Class	K_{st} (bar m/s)	Characteristic
ST 1	1 - 200	Weak explosion
ST 2	201 - 300	Strong explosion
ST 3	> 300	Very strong explosion

Table 4 shows the test results on the sugar and cornstarch samples collected at the Port Wentworth facility. The near-total destruction of the packing building prevented collection of actual sugar dust samples; however, the mean particle size of the powdered sugar is representative of dust that would result from processing granulated sugar. Furthermore, the samples of granulated and powdered sugar were typical of the spilled sugar that had accumulated around equipment in the work areas. In the test chamber, these samples generated significant overpressures of 5.2 bar (76.4 psig) and 7.5 bar (110.2 psig), respectively. A primary event fueled by airborne sugar dust would most likely loft and ignite sugar that had accumulated on the floor or equipment, causing secondary and tertiary dust explosions.

Table 4. Test results of samples collected from the Port Wentworth facility

Material	Moisture Content (wt.%)	Mean Particle Size (µm)	P_{max} [bar]	K_{ST} [bar m/s]	MEC [g/m³]	MIE [mJ]
Cornstarch	11.5	10	8.5	189	105	10 < MIE < 30
Powdered Sugar	0.5	23	7.5	139	95	10 < MIE < 30
Granulated Sugar (as received)	0.1	Not determined	5.2	35	115	MIE >1000
Granulated Sugar (sieved to < 500µm)	0.1	286	6.0	56	115	MIE >1000

3.2 Combustible Dust Explosions

Airborne sugar dust or other combustible dust around dust-generating equipment and in the work areas poses an immediate fire or explosion hazard only under specific conditions.[17] Accumulations of combustible dust on horizontal surfaces in the work area are a serious fire hazard because they can ignite and burn. However, dust on horizontal surfaces will not explosively ignite, even when it has accumulated to a depth of an inch or more. Combustible dusts must become airborne and achieve a concentration above the MEC in the air to ignite explosively. In fact, industrial hygiene-based dust concentration limits (concentrations in air that can pose a health hazard) are four to five orders of magnitude lower than the minimum dust concentrations necessary to propagate a dust explosion (Eckhoff, 2003).

A fireball will likely result when airborne combustible dust concentrates above the MEC and comes in contact with an ignition source. The likelihood of explosive ignition increases if the airborne combustible dust is concentrated in a semi-confined or confined workspace. When confined, concentrated, and ignited, airborne sugar dust can generate overpressure sufficient to cause explosive destruction, as indicated by the maximum pressure recorded in a test cell, P_{max} (Table 4).

Immediate explosive ignition is not the only means of causing overpressure damage. If sufficient dust has accumulated inside ducts or other equipment and airborne dust inside the equipment ignites, the pressure wave advancing ahead of the rapidly burning dust cloud will loft additional dust into the air and provide additional fuel to the advancing fireball, further increasing the pressure inside the equipment. This so-called “pressure piling” can cause the equipment to explosively rupture. If the equipment does not rupture, it can provide a conduit for the fireball to travel long distances and ignite fires or rupture equipment far from the ignition source. Some dust collection ducts and screw

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[17] The approximate concentration of a typical combustible dust in an airborne dust cloud needed to sustain combustion would reduce visibility to 5 to 10 feet. Actual cloud density depends on the dust particle size and minimum concentration needed to sustain combustion.

conveyors in the Port Wentworth facility acted as conduits and ignited fires and ruptured equipment hundreds of feet from the packing building where the incident originated (Figure 12).

Figure 12. Pressure waves traveled through screw conveyors and ruptured steel bulk granulated sugar bins (arrows) hundreds of feet from the sources of the dust explosions

Similarly, if a burning dust cloud is confined inside a building or small structure, combustible dust that has accumulated on overhead horizontal surfaces and the floor can be lofted by the initial overpressure and further fuel the advancing fireball. Pressure piling also results when the fireball and pressure wave advance through a structure filled with manufacturing equipment and other large items. The resulting overpressure can heave floors and roofs upward and blow out windows and unreinforced walls, as occurred throughout the Port Wentworth facility sugar packing buildings.[18]

3.3 The Port Wentworth Incident

The CSB concluded that the Port Wentworth manufacturing facility incident was a combination of a primary and multiple secondary dust explosions. The CSB further concluded that the secondary dust explosions would have been highly unlikely had Imperial Sugar performed routine maintenance on sugar conveying and packaging equipment to minimize dust releases and sugar spillage, and promptly

[18] Some steel-framed windows on the south wall of the packing building were blown more than 200 feet.

removed accumulated dust and spilled sugar. When sugar dust and sugar escaped the equipment in the packing buildings, timely housekeeping activities should have been performed to remove accumulations from elevated horizontal surfaces and spilled granulated and powdered sugar on the floors before the sugar accumulated to hazardous levels.[19]

3.3.1 Pre-explosion Sugar Dust Incident History

The Port Wentworth facility operated for more than 80 years without experiencing a devastating dust explosion,[20] even though photographs dating from the 1970s through 2007 and internal correspondence dating to the early 1960s confirmed that significant sugar dust and spilled sugar in the packing buildings and silo penthouse were long-standing problems. In the year preceding the February 2008 explosion, quality audits and worker injury reports documented spilled sugar at “knee deep” levels in some areas.

Workers told the CSB investigators that small fires sometimes occurred in the buildings but were quickly extinguished without escalating to a major incident. Less than two weeks before the February incident, a small explosion in a dry dust collector on the roof of the packing building damaged the dust collector, but was safely vented through the deflagration vent panels. The dust collector had not yet been returned to service at the time of the incident.

Operators reported that the buckets inside bucket elevators throughout the facility sometimes broke loose and fell to the bottom of the elevator. However, they could recall only one incident, some 10 years earlier, where a falling bucket was thought to be the ignition source of a fire involving a bucket elevator in the raw sugar warehouse. That event did not escalate to a major facility fire or explosion.

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[19] For combustible dust with bulk density above 75 pounds per cubic foot, accumulation on elevated horizontal surfaces in rooms with average ceiling height of about ten to twelve feet should not exceed 1/32 inch (NFPA 654, 2006). Elevated surfaces in a typical factory are equal to about 5-10% of the floor area.

[20] Workers recalled explosions in the fourth floor mill room in the 1960s, which did not cause widespread damage.

3.3.2 Steel Belt Conveyor Modifications

The CSB investigators learned through worker interviews that conveying granulated sugar on the steel belt conveyor in the tunnel under silos 1 and 2 generated some sugar dust. When sugar lumps lodged in a silo outlet pipe and blocked the movement of the sugar on the belt, as operators reported sometimes occurred, sugar spilling off the belt would release airborne dust. Before the company enclosed the steel belt conveyor, the dust was released into the large volume of the tunnel. Airflow through the tunnel would also keep the airborne dust concentration low; thus, airborne sugar dust likely never accumulated to an ignitable concentration.

In 2007, Imperial Sugar enclosed the granulated sugar belt conveyors in the penthouse and the tunnel under the silos to address sugar contamination concerns. However, the company did not evaluate the hazards associated with generating and accumulating combustible dust inside the new enclosure. They did not install a dust removal system to ensure that sugar dust did not reach the MEC inside the enclosure.[21] Furthermore, the enclosures were not equipped with deflagration vents to direct overpressure safely out of the building[22, 23] if airborne sugar dust ignited.

3.3.3 Primary Event Location

For more than 80 years, the facility operated the open steel belt conveyor in the silo tunnel without incident. Less than a year after the enclosure was completed, however, the silos and packing buildings were destroyed by devastating explosions and fires. The CSB examined the blast patterns and damage inside the tunnel, at the east and west tunnel openings, and rooms inside the base of the silos directly

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[21] The volume in the new steel belt enclosure was ten times smaller than the silo tunnel volume. Airborne sugar dust could easily accumulate above the MEC in the unventilated enclosure.

[22] Enclosed equipment, such as bucket elevators and closed conveyors, should be designed in accordance with NFPA 654.

[23] Although the enclosure on the belt conveyors in the penthouse could have been designed to safely vent an explosive overpressure outside the building, designing a deflagration vent system for the belt conveyor in the silo tunnel was impractical. That conveyor was located on the ground floor in the center of the building (Figure 5) far from any building exterior wall or roof.

above the silo tunnel (pantleg rooms, see Figure 7) and concluded that the primary dust explosion most likely occurred in the silo tunnel, approximately midway along the length of the steel belt.

Examination of the equipment in the silo tunnel found that every panel used to enclose the 80-foot long steel belt conveyor had been violently blown off the support frame (Figure 13). Panels east of the approximate midpoint of the conveyor (directly under the silo 1–silo 2 abutment) were deflected eastward, and panels west of the midpoint were deflected westward. Pressure damage inside the pantleg rooms above the tunnel was greatest inside the silo 2 pantleg room and least inside silo 3 pantleg room. Major equipment damage was observed at the east entrance of the silo tunnel with all equipment deflections eastward, away from the tunnel. The equipment under silo 3 and outside the west end of the tunnel had damage patterns clearly indicating that a pressure wave traveled west out of the tunnel.[24]

Figure 13. Steel belt covers (arrows) crumpled from an initial dust explosion inside the steel belt enclosure (steel frame structure, right photo)

Pressure waves blew the wood walls and doors off the west and east tunnel entrances. Mangled steel belt cover panels were blown out of the east end of the tunnel (Figure 14). The pressure wave also

[24] The east face of the Aerobelt under silo 3 was distorted to the west as the explosive overpressure moved through the tunnel.

traveled up between silos 1 and 2 and blew the brick walls that enclosed the south stairwell into the work areas on each floor of the south packing building (Figure 15).

Figure 14. Stainless steel cover panels (arrows) blown off the steel belt enclosure and out of the tunnel into the packing building

Figure 15. South stairwell brick walls blown into the packing building

3.3.4 Primary Event Combustible Dust Source

The CSB learned that, during the 3 to 4 days preceding the incident, workers were clearing sugar lumps lodged in the silo 1 sugar discharge holes above the steel belt. Through access ports in the pantleg room (Figure 16), they used steel rods to break and dislodge sugar lumps found above and inside the sugar discharge holes. Workers also used access ports located on the discharge chutes to break lumps that lodged on the steel belt, blocking sugar flow from the upstream discharge chutes (Figure 17).

During the silo 1 "rodding" activities, sugar continued to flow from silo 2 onto the steel belt upstream of the silo 1 discharge chutes. Based on the statements from the workers who were clearing the sugar lumps from the silo outlets, it is highly likely that sugar lumps lodged between the moving steel belt and one or both silo 1 discharge chutes. Sugar lumps small enough to enter the discharge chute, but too large to pass between the end of the chute and the steel belt would create a "dam" that would cause sugar traveling from silo 2 to spill off the steel belt upstream of the silo 1 discharge chute. Spilled sugar would then accumulate inside the covered conveyor, likely covering parts of the steel belt.[25] Sugar dust released into the air from the sugar spilling off the conveyor, and sugar dust generated as the steel belt traveled through the sugar pile, below, could accumulate in the unventilated enclosure.

[25] The steel belt return loop was fewer than 10 inches above the tunnel floor. Workers reported that spilled granulated sugar sometimes covered the belt return loop and support bearings.

Figure 16. Access port inside the pantleg room and steel rod used to break sugar lumps in the sugar outlet on silo floor

Figure 17. Limited clearance between sugar discharge chute and the steel belt would sometimes be blocked by large sugar lumps; lump-clearing access port (arrow) is on top of the chute

The CSB concluded that as granulated sugar spilled off the moving steel conveyor at the blocked outlet, sugar dust accumulated above the MEC inside the enclosed conveyor, and then ignited. The explosion triggered a series of secondary explosions that rapidly progressed through the packing buildings, palletizer room, and into the bulk sugar station.

3.3.5 Secondary Dust Explosions

The primary dust explosion in the silo tunnel sent overpressure waves into the three silo pantleg rooms,[26] and then out into the first floor of the Bosch building. Explosion pressure waves traveled between silos 1 and 2 and exited into the south stairwell, blowing the brick walls out into the packing building. Sugar dust accumulations on elevated surfaces and spilled sugar on the floors around the packaging equipment contributed to the explosion energy.

The fireballs continued to be fueled by sugar dust dislodged from overhead equipment. Powdered and granulated sugar added fuel as sugar was thrown into the air by the advancing pressure waves. The pressure waves also violently heaved concrete floors upward throughout the south packing building (Figure 18). Spilled sugar that had accumulated on the floors around conveyors and packaging equipment rained into the rooms below adding more fuel to the advancing fireballs.

Appendix A describes the explosions' and fires' progression and resulting facility damage. Appendix B displays the blast patterns and worker locations in the buildings at the time of the incident.

Figure 18. Three-inch thick concrete floor slabs lifted off the steel supports by the explosion pressure waves

[26] Each pantleg room had up to four 12-inch diameter holes through the floor into the tunnel below.

3.4 Ignition Sources

Combustible dust can be ignited by electrical sparks or static discharge, hot surfaces, open flames, or friction-induced hot surfaces or sparks. Controlling possible ignition sources wherever combustible dust is present helps minimize the chance of a fire or explosion.

3.4.1 Open Flames and Hot Surfaces

Imperial Sugar had policies and procedures to control open flames. Workers were permitted to smoke only in designated areas, which were away from the production or packaging equipment. The hot work permit procedure required the workers to control combustible materials and post a fire watch whenever they performed welding or other hot work activities.

The CSB obtained photographs taken in the fall of 2006 that showed large electric motors covered with sugar dust (Figure 19), a condition that could cause the motors to overheat and possibly ignite the spilled sugar or airborne sugar dust. These poor housekeeping practices likely contributed to, or directly resulted in, some of the small sugar fires that sometimes occurred.

Workers told the CSB investigators that occasionally, small incipient stage fires[27] occurred in the packing buildings when sugar or packaging materials was ignited by a hot electrical device or a hot bearing. However, none of these earlier incidents ever resulted in a large fire or involved airborne dust. The CSB ruled out open flame as a possible ignition source for the February 2008 incident.

[27] "Incipient stage fire" is a fire that is in the initial or beginning stage and that can be controlled or extinguished by portable fire extinguishers, a Class II standpipe, or small hose systems without the need for protective clothing or breathing apparatus [29 CFR 1910.155(c)(26)].

Figure 19. Motor cooling fins and fan guard covered with sugar dust; large piles of sugar cover the floor (Imperial Sugar photo)

3.4.2 Ignition Sources Inside the Steel Belt Enclosure

The CSB concluded that the initiating event was most likely the ignition of an explosive concentration of sugar dust within the steel belt enclosure under silos 1 and 2. Multiple possible ignition sources were identified during examination of the damaged steel belt and discussions with operations and maintenance personnel. However, the extent of the destruction from the explosions and long-burning fires prevented identifying a likely ignition source for the primary explosion.

3.4.2.1 Electric Spark Ignition

Because the four limit switches on the steel belt conveyor were located inside the newly installed enclosure, they were exposed to airborne sugar dust. Examination of two of the four switches that survived the fires showed that they were rated explosion proof. Therefore, the CSB concluded the switches most likely were not the ignition source of the primary dust explosion.

3.4.2.2 Hot Surface Ignition

Experiments have been conducted on various combustible dusts to measure the minimum ignition temperatures (MIT) of a dust cloud. Sugar MITs range from 360°C to 420°C (680°F to 788°F), depending on the test apparatus used. Similar experiments involving combustible dusts have been conducted to examine the influence of the time a combustible dust cloud remains in the test apparatus (i.e., residence time, from 0.1-0.4 seconds). Those experiments found that the MIT decreases as the residence time of the dust in the test furnace increases (Eckhoff, 2003). Airborne combustible dust was likely always present when sugar was being transported inside the enclosed steel belt conveyor, especially when blockages caused the granulated sugar to spill off the steel belt.

Operators told the CSB investigators that bearings on the steel belt roller supports sometimes malfunctioned and "got very hot." A hot bearing inside the enclosed steel belt conveyor could ignite airborne sugar dust, especially if the dust remained in contact with the hot surface for many seconds, as it likely did in the unventilated enclosure. Also, if sugar in contact with a hot surface begins to smolder, combustion gases that are released will mix with the airborne sugar dust and decrease the ignition temperature below the ignition temperature of pure sugar dust (Eckhoff, 2003).

3.4.2.3 Friction Sparks

Although not ruled out, the least likely ignition source could have been from metal-to-metal sliding between the steel belt and a jammed support wheel or the steel enclosure frame. Testing has demonstrated that sparks from carbon steel sliding contact are unlikely to ignite combustible dust unless the contact speed exceeds 30.1 feet per second (9.2 meters per second) (Dahn, 1986). The steel conveyor belt operating speed was estimated to be less than 5 feet per second (1.5 meters per second).

3.5 Worker Training

Imperial Sugar conducted routine subject-specific worker training for employees and contractors. The company's "Specific Safety Rules" policy stated that new workers receive comprehensive safety rule training on the first day of employment. The policy also required workers to attend annual refresher safety training. A day-long, annual training session was conducted once each month. Workers typically attended the training during the month of their birthday, a scheduling practice that led to the safety training being called "Birthday Safety Training." Interviews showed that most, but not all, personnel received their safety training in a timely fashion in accordance with the "Specific Safety Rules" policy requirements.

"Birthday Safety Training" subjects in 2006 and 2007 included personal protective equipment, lockout/tagout procedures, confined space entry, fall protection, manlift operation, forklift operation, fire extinguisher operation, compressed air nozzle use, safe and at-risk behaviors, employee self (safety) audits, Material Safety Data Sheets, emergency communication, workers compensation, and maritime security. Interviews revealed minimal retention of the topics covered: while some employees said that the hazard of dust accumulation was included at some time in the training sessions, a review of more than 10,000 pages of "Birthday Safety Training" and "Plant Rules and Guidelines" tests revealed no such coverage since 2005. Furthermore, the training materials did not contain information about combustible dust, and no other documents were provided to verify that training on the hazard of dust accumulation occurred prior to 2005. Although "Birthday Safety Training" extensively covered site safety issues, the hazard of dust accumulation was not among them and was not included in the site's "Specific Safety Rules."

Imperial Sugar quality assurance and safety personnel were made aware of the OSHA combustible dust national emphasis program[28] in early December 2007. Yet a January 30, 2008, "Safety Focus of the Month" email from the safety manager and the *Written Program-- Housekeeping & Material Storage Program* that was attached made no mention of combustible dust.[29] Failure to understand the hazard and control sugar dust accumulations in the work areas by properly maintaining equipment and performing routine housekeeping led to the massive secondary explosions and fires that claimed the lives of the 14 workers and injured dozens.

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[28] The OSHA Combustible Dust National Emphasis Program, CPL 03-00-006, was issued in October 2007.

[29] The memo said "We will continue to focus on housekeeping, material storage and handling walking/working surfaces, and leaks." However, the memo and the written program did not mention hazardous dust or the OSHA NEP.

Had the company trained the workers on the hazards of combustible sugar dust and adopted an effective dust control program, the secondary dust explosions that devastated the facility would likely not have occurred.

3.6 Hazards Management

3.6.1 Evacuation, Fire Alarms, and Fire Suppression

The written emergency response procedure directed workers to use an intercom system to report an emergency. However, workers told the CSB investigators that the intercom system was not used inside the refinery or packing buildings. Rather, they had to rely on radios and cell phones carried by some personnel to announce or be alerted to an emergency. Having no audible or visual alarm devices in the work areas, some workers had no means of prompt notification in the event of an emergency.

The company had posted emergency evacuation routes, but did not provide work location specific evacuation training to all employees and contractors[30] and did not conduct evacuation drills.

Emergency evacuation lights and illuminated exit signs were provided throughout the facility. However, many workers reported that the explosions and fires caused the normal lighting and many emergency lights to fail. The emergency lights that worked did not provide adequate illumination—some workers had extreme difficulty finding their way out of the darkened buildings. Large, complex mechanical equipment and long package conveyors 3 to 4 feet above the floors (Figure 20) impeded rapid and safe emergency egress in the darkened work areas.

A fire suppression sprinkler system was intended to protect each floor of the packing buildings and the palletizer room. The city water main and an onsite firewater tank and emergency diesel-driven pump provided water to the heat-activated sprinkler heads. However, typical of incidents involving

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[30] As part of the new employee/contractor training process, newly hired workers were told to familiarize themselves with evacuation routes when they reported to their work location.

explosive energy releases, the fire suppression piping system was heavily damaged in the initial explosions and rendered ineffective. Lack of water flow from the fire hydrants around the perimeter of the buildings caused by the ruptured sprinkler systems severely hampered firefighting efforts.

Figure 20. Packaging equipment hindered evacuation in the darkened building

Portable fire extinguishers were located throughout the work areas. Wheeled carts containing as many as 16 portable fire extinguishers were located in sugar packaging areas, such as the south packing building third floor. Workers reported using fire extinguishers to extinguish small fires that sometimes occurred. However, the fire extinguishers were useless against the rapidly progressing fires that quickly engulfed the packing building.

3.6.2 Electrical Systems Design

The NFPA publishes NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas,* which is used to classify hazardous work locations, including locations where combustible dust is or might be present. Electrical devices installed in these “classified” locations should comply with applicable NFPA design standards to minimize ignition sources such as NFPA 654 - *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible*

Particulate Solids. The National Electric Code (NEC) and International Fire Code (IFC) incorporate these and other NFPA standards and guidelines. Local, state, and federal government agencies sometimes incorporate the NEC or IFC into building regulations or worker safety standards.

OSHA standard 1910 Subpart S contains the electrical equipment safety requirements to protect employees in their workplaces. The standard addresses work practices and electrical device maintenance requirements for hazardous locations including electrical devices and wiring installed in locations where combustible dusts or fibers may be present.

Imperial Sugar had no written policy or procedure to require classifying hazardous areas or require electrical devices rated for such locations at the Port Wentworth facility. Some locations at the facility contained significant accumulations of combustible sugar or cornstarch dust (Figure 21). The CSB investigators noted that some electrical devices were rated for use in hazardous work locations, but non-rated devices were also installed in the same location, frequently near the rated devices (Figure 22). The CSB investigators also observed many non-hazard classified electrical devices installed in dusty work areas and equipment enclosures. Furthermore, some electrical devices in dusty areas were poorly maintained, such as having missing covers or open doors on many breaker panels and other electrical enclosures.

Figure 21. Left: Sugar dust accumulation on steel belt drive motor in silo tunnel (Imperial Sugar Co. photo, Oct. 2006). Right: Cornstarch spilled under cornstarch silo (March 2008).

Figure 22. Non-dust rated and rated electrical devices in the silo tunnel

The powdered sugar grinding mills motor control room located on the fourth floor of the south packing building was the only area that contained hazardous dust control features to protect the non-rated electrical switchgear. The room was equipped with a positive pressure air conditioning system and sealed doors to prevent sugar dust from entering the room and accumulating on or near the electrical control equipment.

The south packing building sustained extensive blast damage (report cover photo). The ceilings in areas where sugar dust was present were not protected with a suspended ceiling[31] to minimize dust accumulation on rafters, conduit, conveyors, piping, and other equipment. Elevated areas were infrequently cleaned so sugar dust accumulated to dangerous levels. The secondary explosions were most likely fueled by significant accumulations of sugar dust on elevated surfaces. When the floors heaved from the first series of explosive overpressures, large piles of sugar on the floors (Figure 23) would have been released into the areas below and ignited. Overpressure waves advancing horizontally through the packing buildings would also loft sugar piles into flaming fireballs.

Figure 23. Sugar and dust accumulation on a screw conveyor in the south packing building fourth floor near silo 1 (Imperial Sugar photo)

[31] Suspended ceilings can be designed, installed, and maintained above dusty work areas to prevent airborne dust accumulation on overhead piping, electrical devices, and building structural components.

3.6.3 Sugar Dust Handling Equipment

Transporting granulated and powdered sugar in mechanical conveying devices, and filling bags and boxes in the packaging machines generated sugar dust. To control dust, a duct system connected to wet dust collectors was designed to remove sugar dust from granulated sugar process equipment including some conveyors, bucket elevators, and packaging machines. Dust removal ducts were also located in the silos' penthouse and the tunnel under the silos. The dust collectors used water spray to remove the sugar dust from the air. The water from the collectors was returned to the refinery to recover the dissolved sugar. The roof mounted collectors exhausted the cleaned air outside the building.

The powdered sugar and cornstarch process equipment dust collection system used dry dust collectors. Filter bags inside six dust collectors located on the roof of the south packing building captured the sugar and cornstarch dust. Traveling "blow rings" used compressed-air to dislodge the accumulated sugar from the filter bags. The dislodged sugar fell to the bottom of the filter chamber. It then passed through a rotary valve to containers below the dust collectors.

Explosion vent panels protected the dry dust collectors from excessive overpressure if sugar dust ignited inside a collector. In fact, 10 days before the February incident, a malfunction inside a powdered sugar atomizer resulted in a sugar dust fire and explosion inside one of the dry dust collectors. The explosion panels operated as intended and the dust fire safely vented to the atmosphere.

Although much of the granulated and powdered sugar processing equipment was connected to the dust collection system, it was inadequately maintained and did not effectively remove dust from the equipment. A report submitted to Imperial Sugar management by an independent contractor less than a week before the incident identified the following major problems with the two dust collection systems:[32]

- Air flow in ducts significantly below the minimum dust conveying velocity
- Undersized fans--static pressure too low to transport sugar dust
- Fans operating well below the required performance curve
- Incorrectly installed duct piping
- Duct piping plugged with sugar

In that the dust collection systems were ineffective, the only solution for minimizing sugar dust accumulation to prevent a dust explosion would be timely and effective housekeeping practices to remove the sugar dust from the work areas.

3.6.4 Housekeeping and Dust Control

Workers told CSB investigators that sugar spillage and dust generation were constant problems in the packing buildings. They reported that sugar leaked from worn seals, loose or missing covers, and other breaches in the aging screw conveyors, bucket elevators, hoppers, and other bulk sugar transport devices.

Leaks in the pressurized air ducts used to transport cornstarch, and the occasional powdered sugar packaging machine malfunction, released dust into the work areas. In addition, sugar-filled paper or plastic containers sometimes tore open and spilled their contents as they traveled along the conveyors,[33] generating more sugar dust. However, because the large work areas were typically not equipped with dust removal systems, the dust released from these sources would float in the air and settle on overhead piping, equipment, lights, ceiling support beams, and any other horizontal surface.

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[32] Imperial Sugar management had not had the opportunity to act on the report findings before the February dust explosion occurred.

[33] Packaging machine operators reported spilled sugar frequently was as deep as 2-3 feet.

Packaging machines required frequent cleaning to operate properly. Workers routinely used water or steam, and sometimes industrial vacuum cleaners to remove sugar and sugar dust from equipment and work areas. But they also routinely used compressed air[34] to remove accumulated granulated sugar or sugar dust from packaging equipment. Compressed air cleaning only lofted dust into the air where it would later accumulate on horizontal surfaces in the area. More frequent cleaning was needed to remove dust in the work areas, especially on elevated surfaces, before it accumulated to hazardous levels, but was not routinely performed.

Because Imperial Sugar manufactured and packaged food-grade sugar products, general area cleanliness (removal of trash and other debris) was necessary to prevent product contamination and control rodents. Spilled sugar also presented a slip or trip hazard, especially when wet, as workers reported was often the case throughout the facility.

Written housekeeping policies included planned daily, weekly, and monthly packaging area cleaning schedules, but workers reported that these policies were not effectively implemented. Pre-incident photographs of equipment and packaging areas, worker injury reports in 2006 and 2007, and a December 2007 quality assurance survey provided evidence that the housekeeping practices were inadequate—deep piles of spilled granulated and powdered sugar accumulated around and on equipment, and sugar dust accumulated on floors, equipment, and other elevated horizontal surfaces (Figure 24). Workers interviewed by the CSB investigators reported cleaning activities were seldom performed on hard-to-reach elevated surfaces and some powdered sugar packaging areas frequently had dense sugar dust in the air.[35]

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[34] Compressed air cleaning might be needed to remove combustible dust from inaccessible areas inside equipment. Where compressed air is used, care must be taken to minimize lofting combustible dust into the air. Overhead equipment and structures cleaning frequencies must be sufficient to prevent the displaced dust from accumulating above unsafe levels.

[35] A combustible dust explosion hazard is unlikely unless the dust in the air reduces visibility to a few feet. Employee descriptions indicated that airborne sugar dust minimally impacted visibility. However, the airborne dust accumulated on elevated surfaces throughout the work areas.

Figure 24. Deep piles of sugar accumulated on floors and equipment. Note shield installed above screw conveyor drive motor to deflect sugar dust (Imperial Sugar photos).

3.7 Dust Explosion Hazard Awareness

3.7.1 Imperial Sugar Management and Workers

Correspondence dating to as early as 1961[36] indicates that management and refinery personnel were aware of the explosive nature of sugar dust and the importance of minimizing dust accumulation. An August 1961 internal memo describes a dust explosion in the powdered sugar room. A September 1967 internal memo from a refinery engineer to the executive vice president and treasurer reported that

> This dust problem has become so serious and dangerous in modern refineries…at present, we have so much to correct that is knowingly wrong, there is no need for outside help. We make a lot of dust in the plant and have had a very inefficient dust collecting system[;] consequently, it has been hopeless to try to keep the dry end of our plant clean. We have heavy accumulations of dust in several areas… we hope to improve the house keeping around the silos…

[36] The refinery was then owned and operated by Savannah Sugar Refining Corporation.

> By removing these heavy accumulations of dust on beams, sills, and walls, the fuel for a continuous explosion will be eliminated. This is the reason an explosion will travel from one area to another, wrecking large sections of a plant.

One year later, a September 1968 dust explosion occurred inside the mill room. Refinery workers successfully extinguished the fire but not before significant fire and smoke damage occurred.

The CSB reviewed Imperial Sugar-published MSDSs for granulated and powdered sugar products, both of which warn:

> Explosion: NFPA Class 2 Group G Airborne sugar dust accumulation ignition temperature is 370°C. At airborne concentrations of 0.045 gm/L or higher, sugar dust accumulations are explosive.

Another MSDS on file at Imperial Sugar issued by a cornstarch supplier identified the explosion hazard associated with cornstarch dust and warned: "Avoid procedures which could cause a dust cloud to be formed."

Over the years, combustible dust incidents at sugar refineries worldwide,[37, 38] and small combustible dust incidents at the Port Wentworth facility and other Imperial Sugar facilities were known to company management and employees. However, management action to control dust generation and accumulation was ineffective; thus, combustible dust remained a major workplace hazard.

In 1998, an employee was severely burned by a sugar dust explosion in the powdered sugar mill room at the Imperial Sugar refinery in Sugar Land, Texas. Yet, more than eight years after that incident the corporate safety manager wrote in a memo to senior

[37] On September 25, 1963, an explosion and fire at the sugar beet factory of the Utah-Idaho Company resulted in seven deaths. Damage was estimated at $2.9 million at the time of the incident.

[38] On February 15, 1965, a sugar dust explosion and fire in the American Sugar Company Chalmette Refinery near New Orleans killed three and injured many more. Damage was estimated at $17 million at the time of the incident.

management: “Based on conversations with the quality team at each location, we did not have a formal policy for sanitation/housekeeping at any of our sites,” Still, the draft sanitation/housekeeping policy attached to the memo did not discuss sugar dust. Management did not take adequate action to correct the long-standing hazardous combustible dust conditions in their facilities.

Workers told the CSB investigators that occasionally, small fires occurred in the packing buildings when sugar or packaging material was ignited by a hot electrical device or overheated bearing. As recently as January 2008, one worker observed flames “3 feet high” before he and other workers in the area extinguished the fire with portable fire extinguishers. As noted in Section 3.6.3, the explosion panels on a dust collector were blown open when the dust inside the collector was ignited. None of these events resulted in a widespread fire or secondary dust explosion. Fires and even dust explosions occurred at the Imperial Sugar facilities and other sugar refineries[39] without ever propagating into a secondary dust explosion or large fire. The unsafe work practices continued and the combustible dust hazards were not abated.

The CSB concluded that the small events and near-misses caused company management, and the managers and workers at both the Port Wentworth, Georgia, and Gramercy, Louisiana, facilities to lose sight of the ongoing and significant hazards posed by accumulated sugar dust in the packing buildings. Imperial Sugar management and staff accepted a riskier condition and failed to correct the ongoing hazardous conditions, despite the well-known and broadly published hazards associated with combustible sugar dust accumulation in the workplace.

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[39] In November 2007, an equipment malfunction at the Domino Sugar facility in Baltimore, Maryland, resulted in a dust explosion in the powdered sugar mill room. There were no injuries, but the equipment in the mill room sustained major damage.

The process wherein successful operations continue despite existing rejectable conditions or unsafe behaviors results in relaxing the minimum performance standard without basis is called "normalization of deviance." That is, an organization relaxes the criteria rather than identifying and correcting the underlying causes, so the deviations become the new normal operating condition. Normalization of deviance was a principal organizational flaw that led to the space shuttle Columbia disaster in February 2003. The Columbia Accident Investigation Board (NASA, 2003) concluded that

> [B]oth accidents were 'failures of foresight' in which history played a prominent role. First, the history of engineering decisions on foam and O-ring incidents had identical trajectories that 'normalized' these anomalies, so that flying with these flaws became routine and acceptable.

The concept of normalization of deviance is applicable to any operating system. The Columbia accident involved known hazards in highly complex systems and deviation from clearly defined and predetermined safety limits based on operating history. Similarly, the Imperial Sugar incident involved known hazards and acceptance of a lesser performance standard based on operating history.

Imperial Sugar management was aware of the hazards associated with combustible sugar dust, but in the absence of any major catastrophic incident during many years of facility operation, the hazardous conditions went uncorrected. Management did not enforce adequate equipment design and maintenance practices to control sugar dust and spilled sugar. Furthermore, management did not ensure housekeeping activities were adequate to prevent sugar dust and spilled sugar from accumulating to unsafe levels in the workplace. Then, on February 7, 2008 conditions necessary to propagate a dust explosion aligned to cause the catastrophic explosions and fires that swept through the Port Wentworth facility.

3.7.2 Property Risk Insurers

Property insurance carriers conduct facility audits to determine a client's relative insurance risk. Zurich Services Corporation (Zurich) conducted such an audit of the Port Wentworth facility in April 2007 and submitted a "Property Policyholder Risk Improvement Report" to company management in May 2007, which said

> This entire facility was toured during this visit, to evaluate the physical aspects of property loss prevention … The evaluation consisted of a review of building construction; existing occupancies operations; storage arrangements; general housekeeping; management loss prevention and self-inspections programs…

The CSB investigators reviewed Imperial Sugar documents including photographic records, incident reports, quality assurance self-audits, and employee statements about sugar spillage and dust accumulation dated before and after the Zurich audit. The CSB concluded that typical sugar accumulations shown in the photos contained in this report most likely existed at the time of the audit, and in the months after the auditor visited the site. However, the Zurich audit report did not mention spilled sugar and sugar dust accumulation in the areas visited by the auditor. [40]

Zurich told the CSB that they conduct combustible dust hazard awareness training for their facility auditors. They provided the CSB with copies of two comprehensive combustible dust hazard awareness training slide presentations titled "Dust Explosion Prevention and Control" and "Science of a Dust Explosion." This training was developed by Senior Risk Engineers and contained about 79 pages of combined dust awareness training. In September 2007, both sessions were delivered to their personnel who conduct risk assessments. However, Zurich acknowledged that they did not share these training materials with Imperial Sugar Company or other clients who handle combustible dust.

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[40] The Zurich auditor told the CSB that the company is notified ten days in advance of a planned insurance audit. Furthermore, the audit focused on property loss risk in anticipation of the upcoming hurricane season.

In the three dust explosion incidents investigated by the CSB in 2003 (CTA Acoustics, Inc.; West Pharmaceutical Services, Inc.; and Hayes Lemmerz International), risk insurer facility audits failed to identify combustible dust hazards. The CSB made a formal recommendation to the Risk Insurance Management Society, Inc.[41] to "communicate the findings and recommendations of [the Hayes Lemmerz] report to your members" (CSB, 2005). In response to the recommendation the organization posted a link to the CSB investigation on its website in December 2005, a link that was later removed. Additionally, its website contains no information about risks associated with combustible dust in the workplace.

[41] The Risk Insurance Management Society, Inc. is a not-for-profit organization dedicated to advancing the practice of risk management www.rims.org, 2009.

4.0 Regulatory Analysis

4.1 Georgia Fire Codes

Prior to the Imperial Sugar incident, the state of Georgia did not have specific rules or regulations addressing combustible dust in industrial facilities. However, one month after the refinery explosion, the Georgia Office of Insurance and Safety Fire Commissioner promulgated a new, emergency regulation covering combustible dust: Regulations of the Safety Fire Commissioner Chapter 120-3-24-0.12 *Rules and Regulations for Loss Prevention Due to Combustible Dust Explosions and Fire*.

The regulation establishes minimum fire safety standards and requirements in all facilities that handle combustible particulate solids. Effective January 1, 2010 covered facilities will be required to file an annual registration to the Georgia Safety Fire Commissioner. Other key provisions of the new regulation include

- compliance with applicable International Fire Code and National Fire Protection Association standards addressing combustible dust;
- maintaining a current "Certificate of Registration" issued by the office of the Safety Fire Commissioner;
- written safety procedures;
- employee training and periodic refresher training;
- written evacuation plans and periodic drills;
- annual reports on training and evacuation;
- fire alarm systems and other emergency egress design features as provided in NFPA 101, *Life Safety Code and the International Fire Code*.

4.2 Occupational Safety and Health Administration (OSHA)

In 1983, in response to major industrial accidents involving combustible dust in grain handling industries, OSHA promulgated regulations specifically addressing grain dust hazards. The CSB noted in testimony to the Subcommittee on Employment and Workplace Safety, Senate Health, Education, Labor and Pensions Committee in July 2008 that

> According to OSHAs own review in 2003, this standard has cut deaths and injuries from grain dust explosions and fires by 60%. And as noted in the CSB study, the grain industry itself now credits the standard with helping to make the design of grain handling facilities safer.

The grain handling facilities standard (§1910.272) contains specific requirements for minimizing grain dust hazards, periodic worker training, emergency action plans, and written housekeeping procedures to control hazardous dust. OSHA has not promulgated similar combustible dust workplace safety standards for industries outside the grain handling industry.

Between 2003 and 2008, three major combustible dust explosions and the Imperial Sugar Port Wentworth incident killed 28, seriously injured 119, and resulted in many millions in property damage. In 2005, OSHA issued a Safety and Health Information Bulletin (SHIB), *Combustible Dust in Industry: Preventing and Mitigating the Effects of Fire and Explosions.* The bulletin provided general guidance to industry on controlling combustible dust hazards.

In October 2007, approximately five months before the Imperial Sugar incident, OSHA initiated a National Emphasis Program (NEP) targeting industries where combustible dust could be present in the workplace. The NEP was based on a regional combustible dust Special Emphasis Program OSHA implemented in 2004. The NEP focuses on workplaces where combustible dust hazards are likely to be found, including granulated sugar manufacturing and packaging facilities.

Although the NEP is not a worker safety standard, it provides guidance to OSHA inspectors for applying the General Duty Clause and existing standards, such as the Walking-Working Surfaces standard, to conditions and practices that impact or are related to combustible dust hazards. It does not establish new enforceable combustible dust hazard standards.

In July 2008, OSHA announced that it intends to amend the housekeeping standard (§1910.22) to "more explicitly state what had always been true: that the standard applies to accumulations of dust that contribute to an explosion hazard." [42]

In April 2009, 14 months after the Imperial Sugar incident, OSHA announced it intends to initiate rulemaking on a general industry combustible dust standard. This is the first step in addressing the CSB 2006 *Combustible Dust Study* recommendation that OSHA issue a combustible dust standard to address combustible dust workplace hazards in general industry. Until a new standard is in place, OSHA will continue to apply the Combustible Dust NEP to address combustible dust workplace hazards.

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[42] Written statement from the Assistant Secretary, OSHA, before the subcommittee on Employment and Workplace Safety; Committee on Health, Education, Labor and Pensions; U.S. Senate; July 29, 2008.

5.0 Model Fire Codes

Industry best practices addressing process equipment design and fire detection and suppression systems design for manufacturing facilities that generate combustible dust are contained in many standards. These standards, frequently codified into federal, state, or local regulations, typically apply to new construction or expansions and modifications inside existing facilities. The principle standards that address combustible dust are summarized below.

5.1 National Fire Protection Association

The National Fire Protection Association NFPA 654: *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids* dates to 1945. It is a consensus standard applied to the safe handling, storage, and processing of combustible materials, including sugar dust. Subjects include facility and process design, fugitive dust control and housekeeping, ignition sources, and other prevention topics.

NFPA 61: *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities* contains standards applicable to facilities that process, mill, package, store, or ship dry agricultural bulk materials including sugar and starch and dusts generated from these processes. This standard provides information on facility construction, ventilation, dust control, fire prevention, and other topics.

NFPA 499: *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas* contains standards applicable to facilities where combustible dusts are produced, processed, or handled. It also applies to facilities, like sugar refining and packaging, where combustible dust is released into the atmosphere and might accumulate on surfaces. The recommended practice contains guidelines for classifying areas based on the presence of combustible dust for the purpose of selecting suitable electrical devices to minimize the possibility of ignition.

NFPA 101: *Life Safety Code* contains criteria for construction, fire protection, and occupancy features as well as egress features including fire alarms and evacuation routes.

5.2 International Code Council

The International Code Council (ICC) is a membership association "dedicated to building safety and fire prevention, and developing codes used in residential and commercial buildings." The ICC publishes the International Building Code (IBC) and International Fire Code (IFC).

As noted in Section 4.1, Georgia enacted an emergency rule shortly after the Port Wentworth explosion that adopts much of the IBC addressing combustible dust hazards management. The IBC incorporates the NFPA standards and recommended practices addressing combustible dust as listed above.

Chapter 13 of the IFC covers combustible dust hazards. This one-page chapter provides brief performance requirements addressing the prohibition of ignition sources where combustible dust is generated, stored, manufactured, processed, or handled, and advises that combustible dust accumulations be minimized and not collected by any means that will put combustible dust into the air.

The IFC briefly discusses application of NFPA 654 and NFPA 484, but does not require industry to use them. The IFC "authorizes" the "code official" (the government authority having jurisdiction) to require and enforce "applicable provisions" of the NFPA and other standards included by reference in Chapter 13. Requirements for specific compliance to IFC or other standards are established only through laws and regulations promulgated by local, state, or federal government bodies.

6.0 Trade Associations

6.1 AIB International

Founded in 1919, AIB International (AIB), formerly the American Institute of Baking, provides independent inspections, audits, and training to food processing, distribution, and retail industries worldwide. Although its services focus primarily on food safety and quality, its website states that its staff includes experts in occupational safety and maintenance practices. It reports that the organization provides training on OSHA compliance programs including confined spaces, hot work, lockout/tagout, and other OSHA standards to member companies. AIB also offers a *Safety and Health Management Systems* three-day training course to member companies.

Being a member company in AIB, Imperial Sugar receives annual AIB Good Manufacturing Practice (GMP) audits.[43] The audit assesses company policies, operations, and condition of buildings, production, and storage, among other GMP elements. A “participation certificate” is issued to the company if it passes the audit. A full inspection report is also issued to the company.

AIB audited the Port Wentworth facility in May 2007 and awarded a “superior” rating. However, the audit considered only sugar dust accumulation that might impact food quality and not workplace hazards associated with combustible sugar dust accumulation.

AIB is well-positioned to help member companies become better informed about the hazards associated with combustible dust in food manufacturing facilities. Although the AIB annual audits are intended to address food safety issues, the audit criteria could be amended to include basic reviews of workplace dust hazard awareness and control. Trained auditors could observe conditions in manufacturing facilities and examine hazard communication policies and procedures as part of the

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[43] Membership in AIB and annual AIB audits are contractually required by many Imperial Sugar Co. customers.

annual facility inspection. Furthermore, AIB could revise the *Safety and Health Management Systems* training course to address combustible dust.

6.2 American Bakers Association

Established in 1897, the American Bakers Association (ABA) represents the interests of the wholesale baking industry before the U.S. Congress, federal agencies, state legislatures and agencies, and international regulatory authorities.

> [The]ABA is dedicated to the principles of free enterprise, competition and the economic health of the entire food industry. To that end, ABA's organization functions primarily in the areas of government relations (federal and state), industry relations, communications, conventions and meetings.[44]

The ABA Safety Committee

> is comprised of safety and loss control professionals of the wholesale baking industry....Committee members share strategies to help protect the industry's skilled workforce and reduce workers compensation costs and exposures.

Like the AIB, the ABA can promote improvements in combustible dust hazard awareness and control throughout their membership. It could develop and publish bulletins, or safety guidance similar to its *Confined Space Entry* webinar presentation material, that address combustible dust characteristics including ignition energy, minimum explosible concentration, best practices for proper design and operation to minimizing dust accumulation on elevated surfaces, and safe housekeeping practices.

6.3 The Sugar Association

The Sugar Association, founded by members of the U.S. sugar industry began as the Sugar Research Foundation in 1943. The organization's focus is on the scientific study of sugar's role in food and communication of that role to the public. The Sugar Association's member companies are producers

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[44] http://www.americanbakers.org/about/MissionStmt.htm (February 2008).

and growers of sugar in the United States. The organizations' Board of Directors is comprised of decision-making representatives from each of those companies or groups. Additionally, three advisory committees are made up of member company staff, which assists in guiding the direction of Public Policy, Public Education, and Scientific Affairs for the association. Imperial Sugar Company is a member of the Sugar Association.

6.4 Sugar Industry Technologists

Sugar Industry Technologists, Inc. was established in the United States in 1941 by several North American sugar refiners. It has developed into an international association with a membership of about 50 corporate sugar refining companies including Imperial Sugar, about 50 corporate allied companies, and has more than 500 individual members from around the world.

The organization holds an annual convention, typically in May, where technical sessions are held. At these sessions, members present technical papers based on research or development in cane sugar processing technology, quality control, environmental issues, and other topics of interest to the cane sugar refining industry.

7.0 Previous CSB Dust Explosion Investigations

On January 29, 2003, a massive dust explosion at the West Pharmaceutical Services facility in Kinston, North Carolina, killed six workers and destroyed the facility. Polyethylene powder accumulated on surfaces above the suspended ceiling, providing fuel for a devastating secondary explosion (CSB, 2004).

On February 20, 2003, a series of dust explosions at the CTA Acoustics facility in Corbin, Kentucky, killed seven workers, injured 37, and destroyed the facility. Although management was aware of dust explosion hazards associated with the phenolic resin used in the manufacturing process, inadequate housekeeping and equipment maintenance resulted in dust accumulation to dangerous amounts throughout the production areas, in vent ducting, and in dust collector housings. An overheated open oven ignited airborne resin dust during an area cleaning activity. The concussion from that event caused a massive secondary dust explosion fueled by dust that had accumulated on horizontal surfaces throughout the work areas (CSB, 2004).

On October 29, 2003, an aluminum dust fueled explosion killed one worker and injured several others at Hayes Lemmerz International in Huntington, Indiana. The explosion likely originated in the dust collector, which had not been adequately maintained. The initial explosion spread through dust collector ducting, causing a large fireball to emerge inside the building and fatally burn the worker. The concussion from the primary event lofted aluminum dust that had accumulated on the rafters and other horizontal surfaces inside the building. The secondary explosion injured the other workers and heavily damaged the facility (CSB, 2004).

In 2006, the CSB issued the *Combustible Dust Hazard Study* (CSB, 2006), which identified 281 combustible dust incidents between 1980 and 2005 that killed 119 workers and injured 718 and caused extensive property damage.[45] The CSB study found that the NFPA publishes comprehensive standards on combustible dust hazard minimization that "are widely recognized by experts as effective and authoritative."

The study found that OSHA typically applied the General Duty Clause (Section 5(a)(1)) or a variety of OSHA standards only tangentially related to dust explosion hazards to cite employers only after devastating dust explosions. In contrast, the OSHA Grain Handling Facilities Standard, issued almost 20 years ago, effectively reduced the number and severity of combustible grain dust explosions in the grain handling industry and sets an example of OSHA addressing a similar problem through regulation.

The continuing catastrophic dust incidents presented in the dust study prompted the CSB to issue a recommendation to OSHA in 2006 to issue a comprehensive combustible dust standard for general industry. As discussed in Section 4.2, in April 2009 OSHA took the first step toward implementing the CSB recommendation by announcing that an advanced notice of proposed rulemaking was in development.

[45] As of July 31, 2008, the number of dust incidents had increased to 363.

8.0 Key Findings:

1. Imperial Sugar and the granulated sugar refining and packaging industry have been aware of sugar dust explosion hazards as far back as 1925.

2. Port Wentworth facility management personnel were aware of sugar dust explosion hazards and emphasized the importance of properly designed dust handling equipment and good housekeeping practices to minimize dust accumulation as long ago as 1958, but did not take action to minimize and control sugar dust hazards.

3. Over the years, the facility experienced granulated sugar and powdered sugar fires caused by overheated bearings or electrical devices in the packing building. However, none of these incidents resulted in a devastating sugar dust explosion or major fire before the February 2008 incident.

4. Company management and the managers and workers at both the Port Wentworth, Georgia, and Gramercy, Louisiana, refineries did not recognize the significant hazard posed by sugar dust, despite the continuing history of near-misses.

5. The enclosure installed on the steel conveyor belt under silos 1 and 2 created a confined, unventilated space where sugar dust could easily accumulate above the minimum explosible concentration.

6. The enclosed steel conveyor belt was not equipped with explosion vents to safely vent a combustible dust explosion outside the building.

7. Company management and supervisory personnel had reviewed and distributed the OSHA *Combustible Dust National Emphasis Program* shortly after it was issued in October 2007, but did not promptly act to remove all significant accumulations of sugar and sugar dust throughout the packing buildings and in the silo penthouse.

8. The secondary dust explosions, rapid spreading of the fires throughout the facility, and resulting fatalities would likely not have occurred if Imperial Sugar had enforced routine housekeeping policies and procedures to remove sugar dust from overhead and elevated work surfaces and remove the large accumulations of spilled sugar throughout the packing buildings.

9. The Port Wentworth facility risk assessment performed by Zurich Services Corporation in May 2007 and the report submitted to Imperial Sugar management did not adequately address combustible dust hazards.

9.0 Incident Causes

1. Sugar and cornstarch conveying equipment was not designed or maintained to minimize the release of sugar and sugar dust into the work area.

2. Inadequate housekeeping practices resulted in significant accumulations of combustible sugar and sugar dust on the floors and elevated surfaces throughout the packing buildings.

3. Airborne combustible sugar dust accumulated above the minimum explosible concentration inside the newly enclosed steel belt assembly under silos 1 and 2.

4. An overheated bearing in the steel belt conveyor most likely ignited a primary dust explosion.

5. The primary dust explosion inside the enclosed steel conveyor belt under silos 1 and 2 led to massive secondary dust explosions and fires throughout the packing buildings.

6. The 14 fatalities were most likely the result of the secondary explosions and fires.

7. Imperial Sugar emergency evacuation plans were inadequate. Emergency evacuation drills were not conducted, and prompt worker notification to evacuate in the event of an emergency was inadequate.

10.0 Recommendations

The CSB makes recommendations based on the findings and conclusions of its investigations. Recommendations are made to parties that can effect change to prevent future incidents, which may include the companies involved, industry organizations responsible for developing good practice guidelines, regulatory bodies, and/or organizations that have the ability to broadly communicate lessons learned from the incident, such as trade associations and labor unions.

10.1 Imperial Sugar Company

2008-05-I-GA-R1 Apply the following standards to the design and operation of the new Port Wentworth facility:

- NFPA 61: *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*
- NFPA 499-*Recommended Practice for the Classification of Combustible Dusts and Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*.
- NFPA 654-*Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*.
- NFPA Handbook, *Electrical Installations in Hazardous Locations.*
- NFPA 70, Article 500 - *Hazardous (Classified) Locations.*

2008-05-I-GA-R2 Conduct a comprehensive review of all existing Imperial Sugar Company sugar manufacturing facilities against the standards listed in recommendation R1 and implement identified corrective actions.

2008-05-I-GA-R3 Implement a corporate-wide comprehensive housekeeping program to control combustible dust accumulation that will ensure sugar dust, cornstarch dust, or other combustible dust does not accumulate to hazardous quantities on overhead horizontal surfaces, packing equipment, and floors.

2008-05-I-GA-R4 Develop training materials that address combustible dust hazards and train all employees and contractors at all Imperial Sugar Company facilities. Require periodic (e.g., annual) refresher training for all employees and contractors.

2008-05-I-GA-R5 Improve the emergency evacuation policies and procedures at the Port Wentworth facility; specifically,

- Install an emergency alert (alarm) system in the facility, and
- Require routine emergency evacuation drills and critiques

10.2 AIB International

2008-05-I-GA-R6 Incorporate combustible dust hazard awareness into employee and member companies' training programs, such as the Safety and Health Management Systems training course. Include combustible dust characteristics, especially ignition energy and minimum explosible concentration; best practices for minimizing dust accumulation, especially on elevated surfaces; and safe housekeeping practices.

2008-05-I-GA-R7 Add specific combustible dust inspection requirements and metrics to the Food Contact Packaging Facility audit procedures.

10.3 American Bakers Association

2008-05-I-GA-R8 Actively promote improvements in combustible dust hazard awareness and control throughout the wholesale baking industry by publishing bulletins or safety guidance that address combustible dust characteristics including ignition energy, minimum explosible concentration, best practices for minimizing dust accumulation, and safe housekeeping practices.

10.4 Risk Insurance Management Society, Inc

2008-05-I-GA-R9 Require member companies to

- Develop and implement combustible dust hazard awareness training for all facility audit personnel, and
- Incorporate combustible dust hazard identification in the audit protocols.

10.5 Zurich Services Corporation

2008-05-I-GA-R10 Ensure that all risk engineers are trained in the hazards of combustible dust, and that refresher training occurs at regular intervals. Provide a copy of your combustible dust hazard awareness training materials to your clients who deal with combustible dust.

10.6 Occupational Safety and Health Administration

2008-05-I-GA-R11 Proceed expeditiously, consistent with the Chemical Safety Board's November, 2006 recommendation and OSHA's announced intention to conduct rulemaking, to promulgate a comprehensive standard to reduce or eliminate hazards from fire and explosion from combustible powders and dust.

11.0 REFERENCES

Babrauskas, V. *Ignition Handbook*, Fire Science and Technology, Inc., Issaquah, WA.2003.

Center for Chemical Process Safety (CCPS). *Guidelines for Safe Handling of Powders and Bulk Solids*, AIChE/CCPS, New York, NY, 2005.

Chou, C.C. *Handbook of Sugar Refining*, Sugar Processing Research Institute, Inc., John Wiley & Sons, Inc. New York, 2000.

Crowl, D.A. *Understanding Explosions*, American Institute of Chemical Engineers (AIChE), New York, NY, 2003.

Dahn, J.C.; Reyes, B.N., Determination of Metal Sparking Characteristics and the Effects on Explosive Dust Clouds," *Industrial Dust Explosions*, ASTM Special Technical Publication 958, Philadelphia, PA, 1986.

Dastidar, A.G. et. al., "Evaluation of Dust and Hybrid Mixture Explosion Potential in Process Plants," *Process Safety Progress.* Vol. 24, No. 4, December 2005.

Eckhoff, R. *Dust Explosions in the Process Industries,* 3rd ed. Gulf Professional Publishing, Houston, TX, 2003.

Gibbs, W.E. *The Dust Hazard in Industry*. Richard Clay & Sons, Ltd., Bungay, Suffolk, U.K, 1925.

International Code Council, *International Fire Code,* Falls Church, VA, 2006 ed.

National Fire Protection Association (NFPA) NFPA 61. *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, Quincy, MA, 2008.

NFPA 70, *National Electric Code*, Article 500 - Hazardous (Classified) Locations, 2008 ed.

NFPA 101, *Life Safety Code,* 2009 ed.

NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas,* 2008 ed.

NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids,* 2006 ed.

U.S. Chemical Safety Board (CSB). *Investigation Report, Dust Explosion, West Pharmaceutical Services, Inc.,* U.S. Chemical Safety and Hazard Investigation Board (CSB), September 2004.

CSB. *Investigation Report. Combustible Dust Fire and Explosions, CTA Acoustics, Inc*., U.S. Chemical Safety and Hazard Investigation Board, February 2005.

CSB. *Investigation Report. Aluminum Dust Explosion, Hayes Lemmerz International-Huntington, Inc*., U.S. Chemical Safety and Hazard Investigation Board, September 2005.

CSB. *Investigation Report, Combustible Dust Hazard Study,* Investigation Number 2006-H-1, U.S. Chemical Safety and Hazard Investigation Board, November 2006.

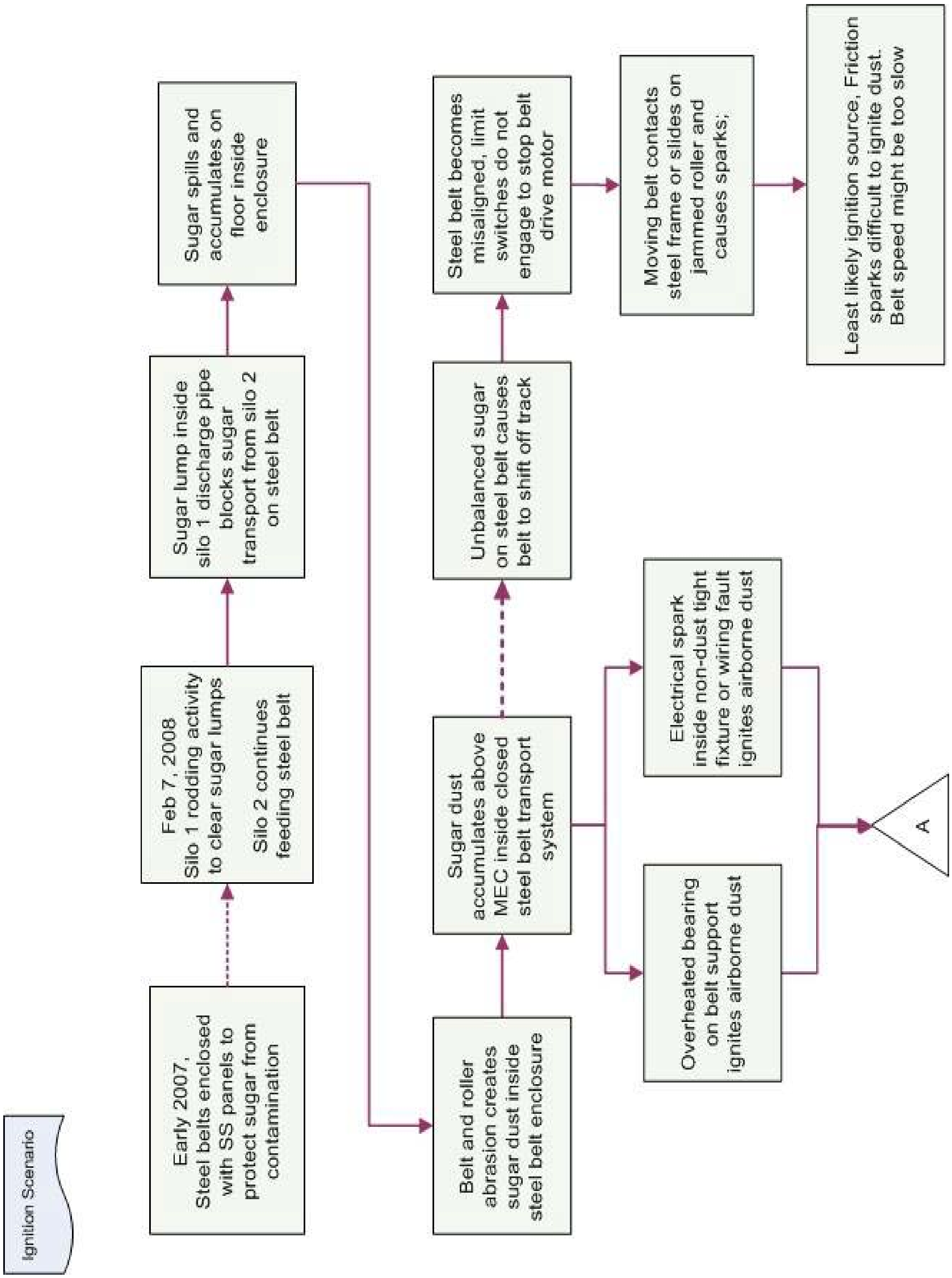
U.S. National Aeronautics and Space Administration (NASA). *Columbia Accident Investigation Board Final Report*, Government Printing Office, Washington, DC, 2003.

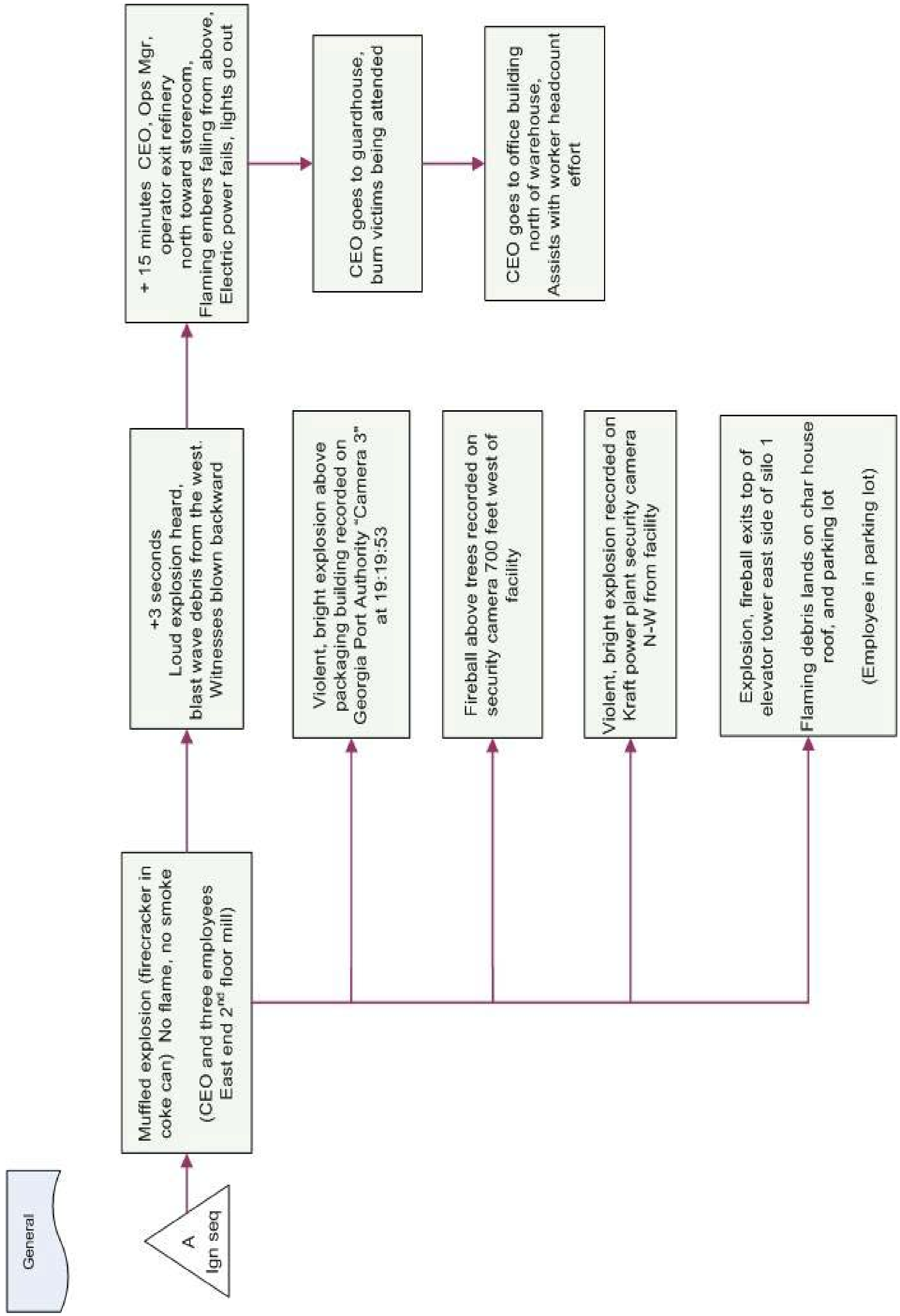
U.S. Occupational Safety and Health Administration (OSHA). *Combustible Dust in Industry: Preventing and Mitigating the Effects of Fire and Explosions,* Safety and Health Information Bulletin SHIB, July 31, 2005.

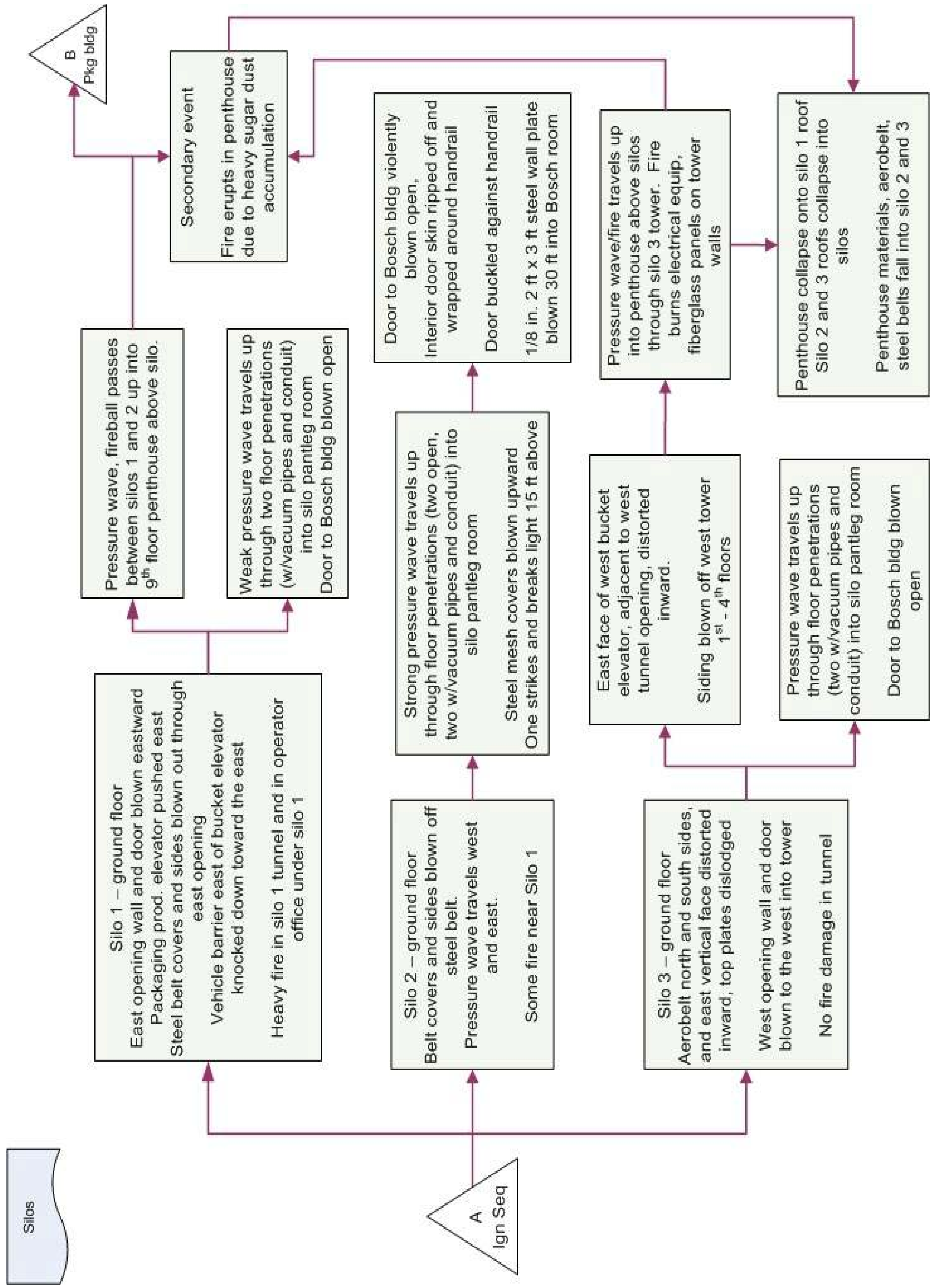
OSHA. C*ombustible Dust National Emphasis Program,* CPL 03-00-006, October 18, 2007, reissued as CPL 03-00-008, March 11, 2008.

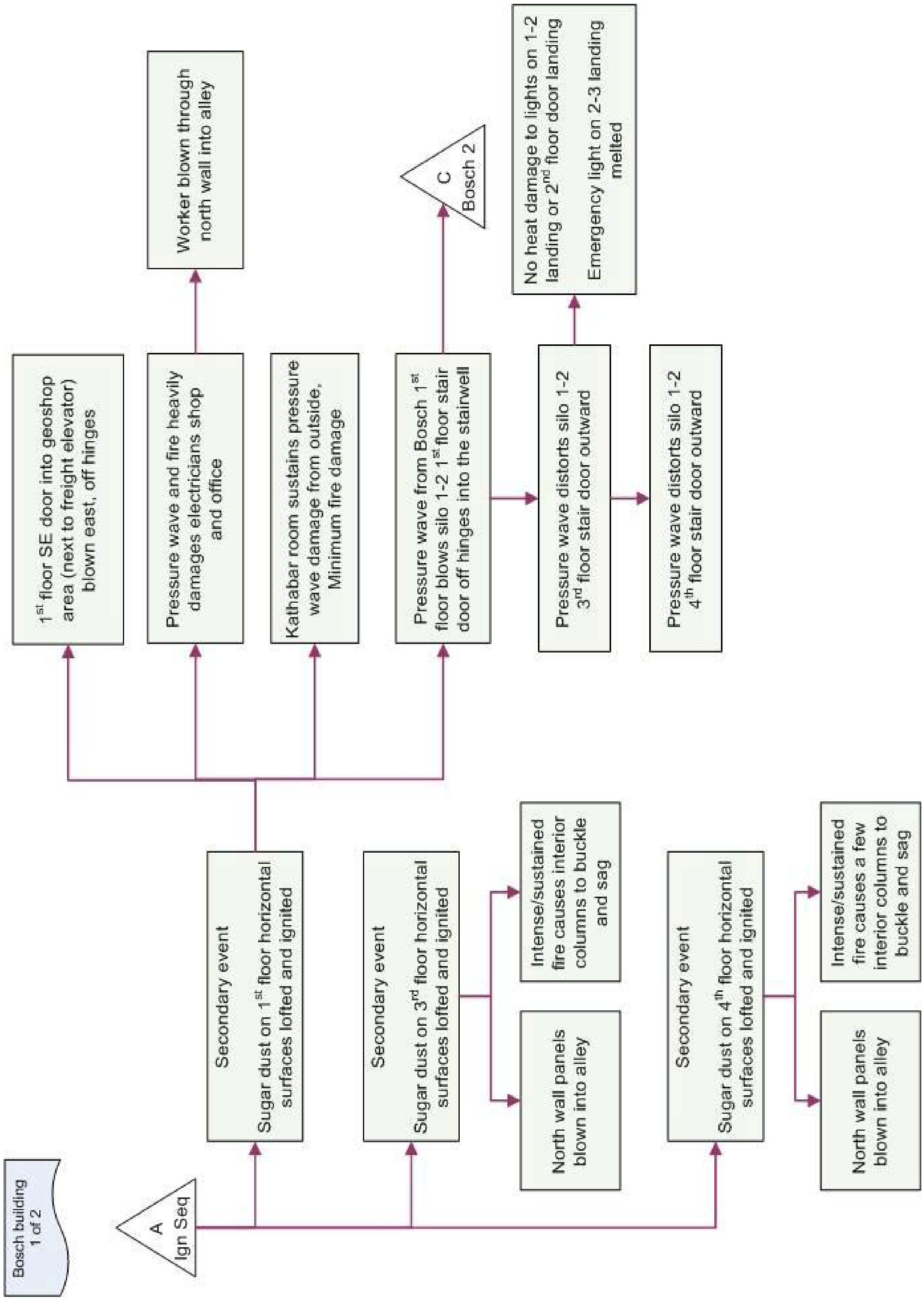
Wheeler, R.V. *Coal Dust Explosions, Eskmeals,* H.M. Stationery Office, U.K., 1924.

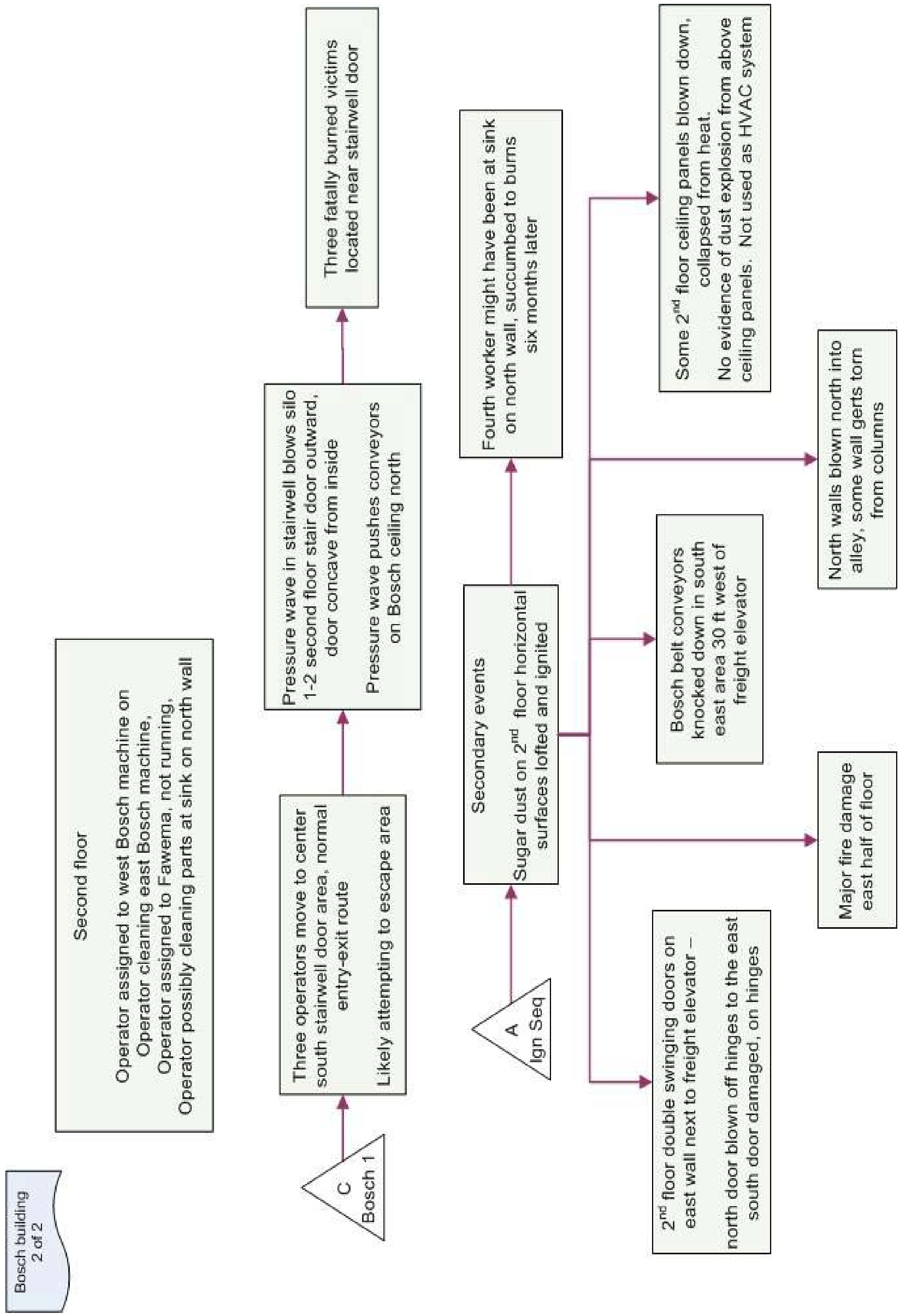
Appendix A – Incident Event Sequence

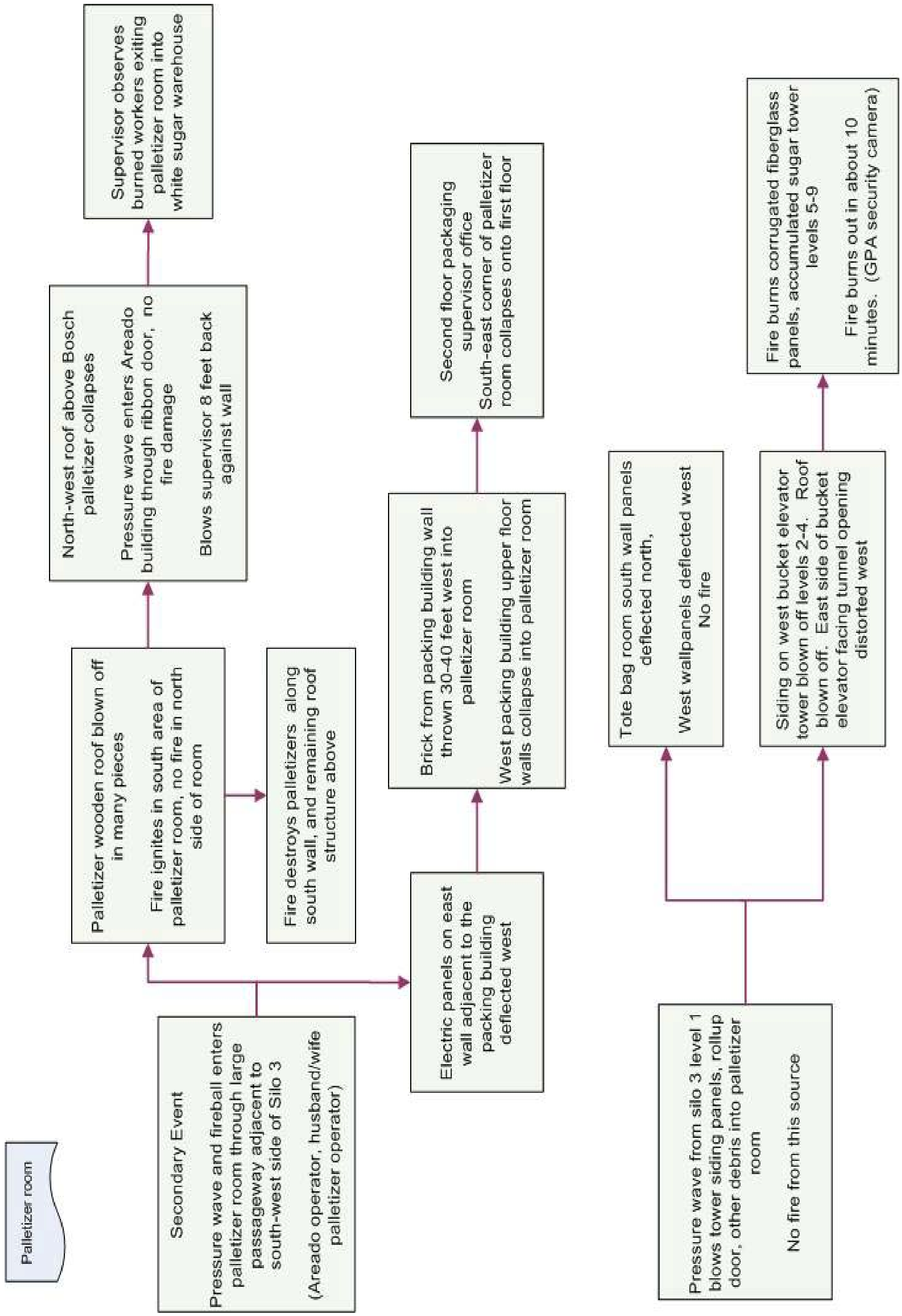

Ignition Scenario
Early 2007, Steel belts enclosed with SS panels to protect sugar from contamination
Feb 7, 2008 Silo 1 rodding activity to clear sugar lumps
Silo 2 continues feeding steel belt
Sugar lump inside silo 1 discharge pipe blocks sugar transport from silo 2 on steel belt
Sugar spills and accumulates on floor inside enclosure
Belt and roller abrasion creates sugar dust inside steel belt enclosure
Sugar dust accumulates above MEC inside closed steel belt transport system
Unbalanced sugar on steel belt causes belt to shift off track
Steel belt becomes misaligned, limit switches do not engage to stop belt drive motor
Moving belt contacts steel frame or slides on jammed roller and causes sparks;
Least likely ignition source, Friction sparks difficult to ignite dust. Belt speed might be too slow
Overheated bearing on belt support ignites airborne dust
Electrical spark inside non-dust tight fixture or wiring fault ignites airborne dust
A

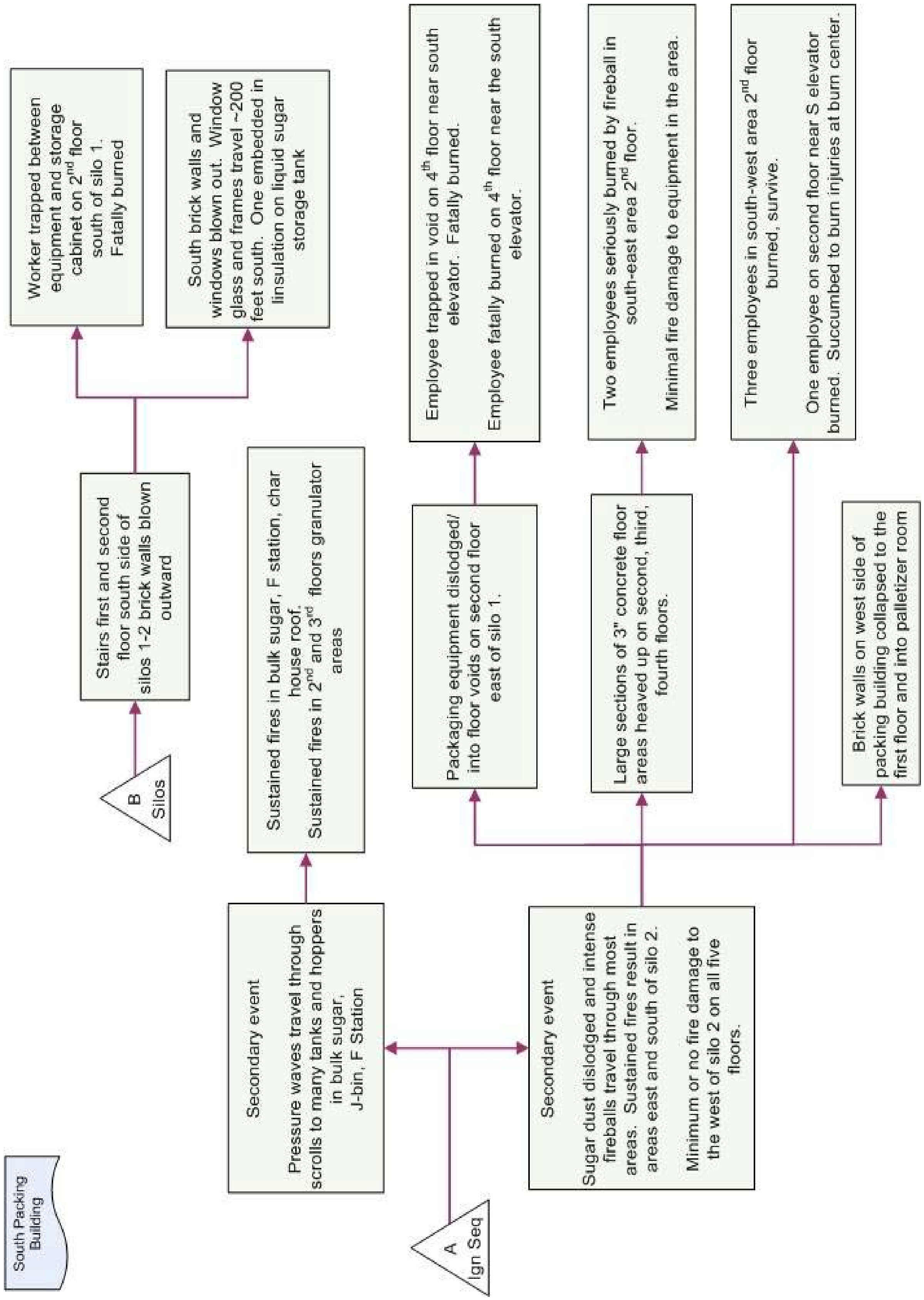

General
A
Ign seq
Muffled explosion (firecracker in coke can) No flame, no smoke
(CEO and three employees East end 2nd floor mill)
+3 seconds
Loud explosion heard, blast wave debris from the west. Witnesses blown backward
+ 15 minutes CEO, Ops Mgr, operator exit refinery north toward storeroom, Flaming embers falling from above, Electric power fails, lights go out
CEO goes to guardhouse, burn victims being attended
CEO goes to office building north of warehouse, Assists with worker headcount effort
Violent, bright explosion above packaging building recorded on Georgia Port Authority "Camera 3" at 19:19:53
Fireball above trees recorded on security camera 700 feet west of facility
Violent, bright explosion recorded on Kraft power plant security camera N-W from facility
Explosion, fireball exits top of elevator tower east side of silo 1
Flaming debris lands on char house roof, and parking lot
(Employee in parking lot)

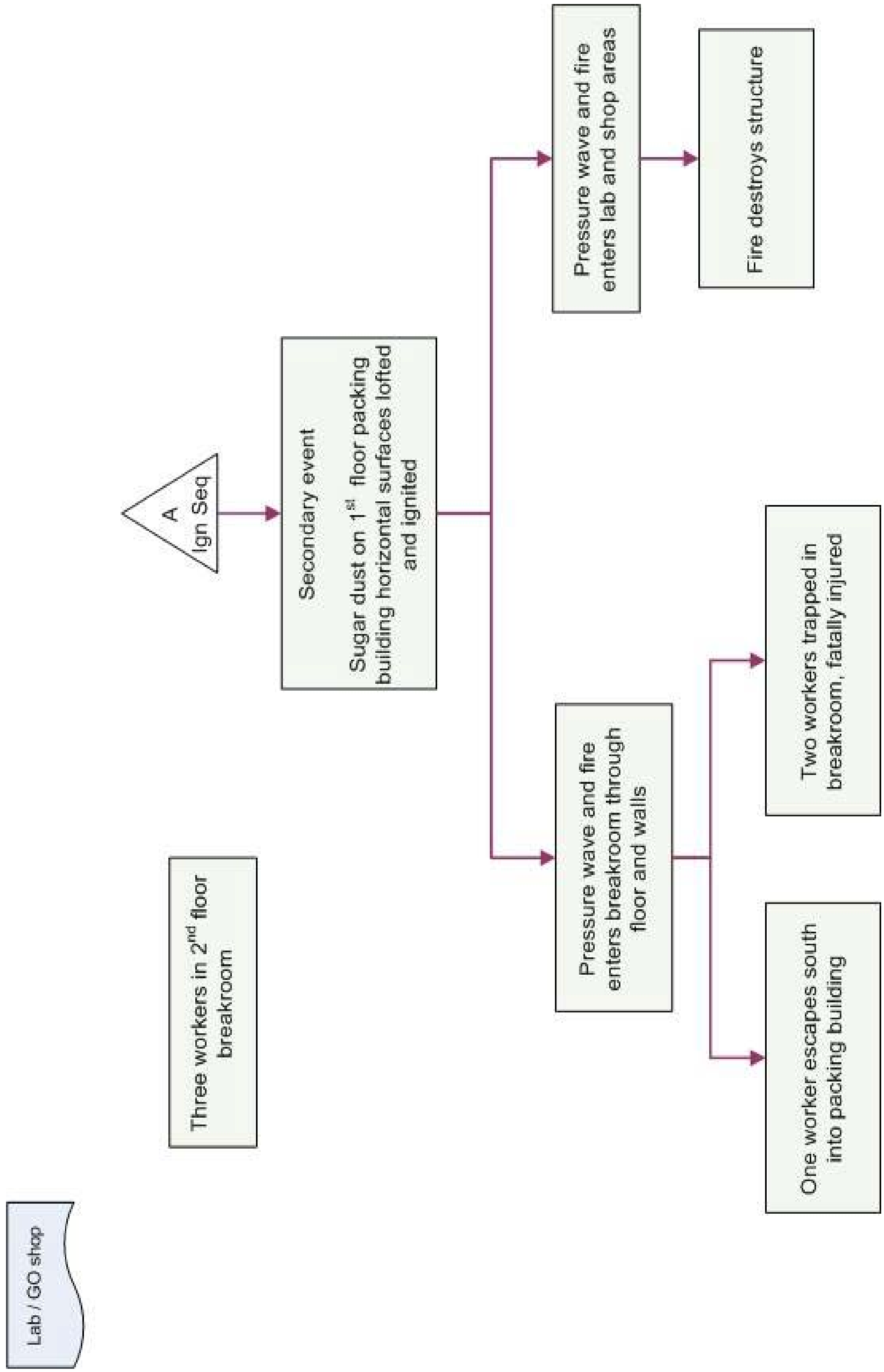

Silos
A
Ign Seq
Silo 1 – ground floor
East opening wall and door blown eastward
Packaging prod. elevator pushed east
Steel belt covers and sides blown out through east opening
Vehicle barrier east of bucket elevator knocked down toward the east
Heavy fire in silo 1 tunnel and in operator office under silo 1
Pressure wave, fireball passes between silos 1 and 2 up into 9th floor penthouse above silo.
Weak pressure wave travels up through two floor penetrations (w/vacuum pipes and conduit) into silo pantleg room
Door to Bosch bldg blown open
Secondary event
Fire erupts in penthouse due to heavy sugar dust accumulation
B
Pkg bldg
Silo 2 – ground floor
Belt covers and sides blown off steel belt.
Pressure wave travels west and east.
Some fire near Silo 1
Strong pressure wave travels up through floor penetrations (two open, two w/vacuum pipes and conduit) into silo pantleg room
Steel mesh covers blown upward
One strikes and breaks light 15 ft above
Door to Bosch bldg violently blown open,
Interior door skin ripped off and wrapped around handrail
Door buckled against handrail
1/8 in. 2 ft x 3 ft steel wall plate blown 30 ft into Bosch room
Silo 3 – ground floor
Aerobelt north and south sides, and east vertical face distorted inward, top plates dislodged
West opening wall and door blown to the west into tower
No fire damage in tunnel
East face of west bucket elevator, adjacent to west tunnel opening, distorted inward.
Siding blown off west tower 1st - 4th floors
Pressure wave/fire travels up into penthouse above silos through silo 3 tower. Fire burns electrical equip, fiberglass panels on tower walls
Pressure wave travels up through floor penetrations (two w/vacuum pipes and conduit) into silo pantleg room
Door to Bosch bldg blown open
Penthouse collapse onto silo 1 roof
Silo 2 and 3 roofs collapse into silos
Penthouse materials, aerobelt, steel belts fall into silo 2 and 3


Bosch building
1 of 2
A
Ign Seq
Secondary event
Sugar dust on 1st floor horizontal surfaces lofted and ignited
Secondary event
Sugar dust on 3rd floor horizontal surfaces lofted and ignited
Secondary event
Sugar dust on 4th floor horizontal surfaces lofted and ignited
North wall panels blown into alley
Intense/sustained fire causes interior columns to buckle and sag
North wall panels blown into alley
Intense/sustained fire causes a few interior columns to buckle and sag
1st floor SE door into geoshop area (next to freight elevator) blown east, off hinges
Pressure wave and fire heavily damages electricians shop and office
Worker blown through north wall into alley
Kathabar room sustains pressure wave damage from outside, Minimum fire damage
Pressure wave from Bosch 1st floor blows silo 1-2 1st floor stair door off hinges into the stairwell
C
Bosch 2
Pressure wave distorts silo 1-2 3rd floor stair door outward
No heat damage to lights on 1-2 landing or 2nd floor door landing
Emergency light on 2-3 landing melted
Pressure wave distorts silo 1-2 4th floor stair door outward

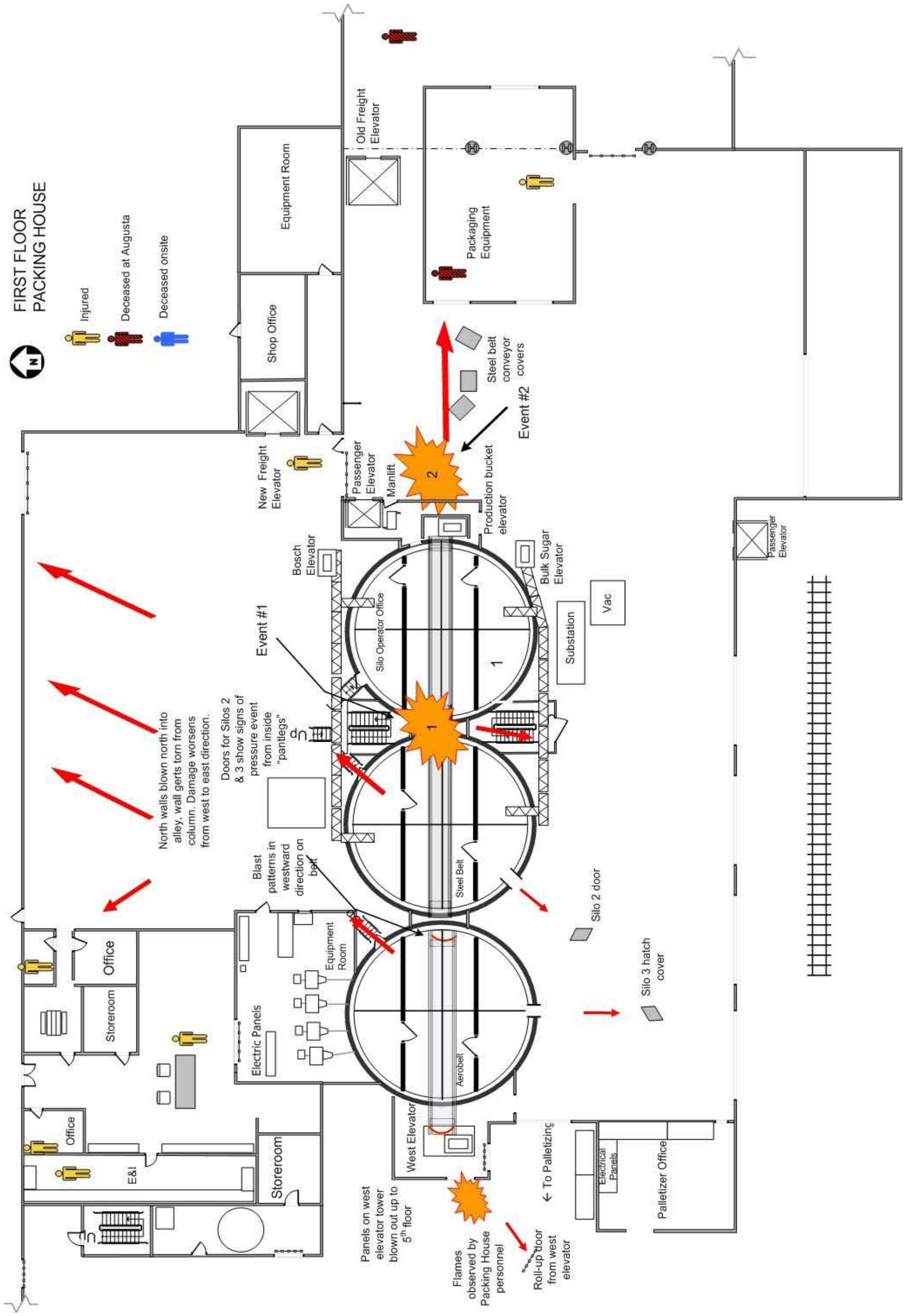

Bosch building 2 of 2
Second floor
Operator assigned to west Bosch machine on
Operator cleaning east Bosch machine,
Operator assigned to Fawema, not running,
Operator possibly cleaning parts at sink on north wall
C Bosch 1
Three operators move to center south stairwell door area, normal entry-exit route
Likely attempting to escape area
Pressure wave in stairwell blows silo 1-2 second floor stair door outward, door concave from inside
Pressure wave pushes conveyors on Bosch ceiling north
Three fatally burned victims located near stairwell door
A Ign Seq
Secondary events
Sugar dust on 2nd floor horizontal surfaces lofted and ignited
Fourth worker might have been at sink on north wall, succumbed to burns six months later
2nd floor double swinging doors on east wall next to freight elevator –
north door blown off hinges to the east south door damaged, on hinges
Major fire damage east half of floor
Bosch belt conveyors knocked down in south east area 30 ft west of freight elevator
North walls blown north into alley, some wall gerts torn from columns
Some 2nd floor ceiling panels blown down, collapsed from heat.
No evidence of dust explosion from above ceiling panels. Not used as HVAC system


Palletizer room
Secondary Event
Pressure wave and fireball enters palletizer room through large passageway adjacent to south-west side of Silo 3
(Areado operator, husband/wife palletizer operator)
Palletizer wooden roof blown off in many pieces
Fire ignites in south area of palletizer room, no fire in north side of room
Fire destroys palletizers along south wall, and remaining roof structure above
North-west roof above Bosch palletizer collapses
Pressure wave enters Areado building through ribbon door, no fire damage
Blows supervisor 8 feet back against wall
Supervisor observes burned workers exiting palletizer room into white sugar warehouse
Electric panels on east wall adjacent to the packing building deflected west
Brick from packing building wall thrown 30-40 feet west into palletizer room
West packing building upper floor walls collapse into palletizer room
Second floor packaging supervisor office
South-east corner of palletizer room collapses onto first floor
Pressure wave from silo 3 level 1 blows tower siding panels, rollup door, other debris into palletizer room
No fire from this source
Tote bag room south wall panels deflected north,
West wallpanels deflected west
No fire
Siding on west bucket elevator tower blown off levels 2-4. Roof blown off. East side of bucket elevator facing tunnel opening distorted west
Fire burns corrugated fiberglass panels, accumulated sugar tower levels 5-9
Fire burns out in about 10 minutes. (GPA security camera)

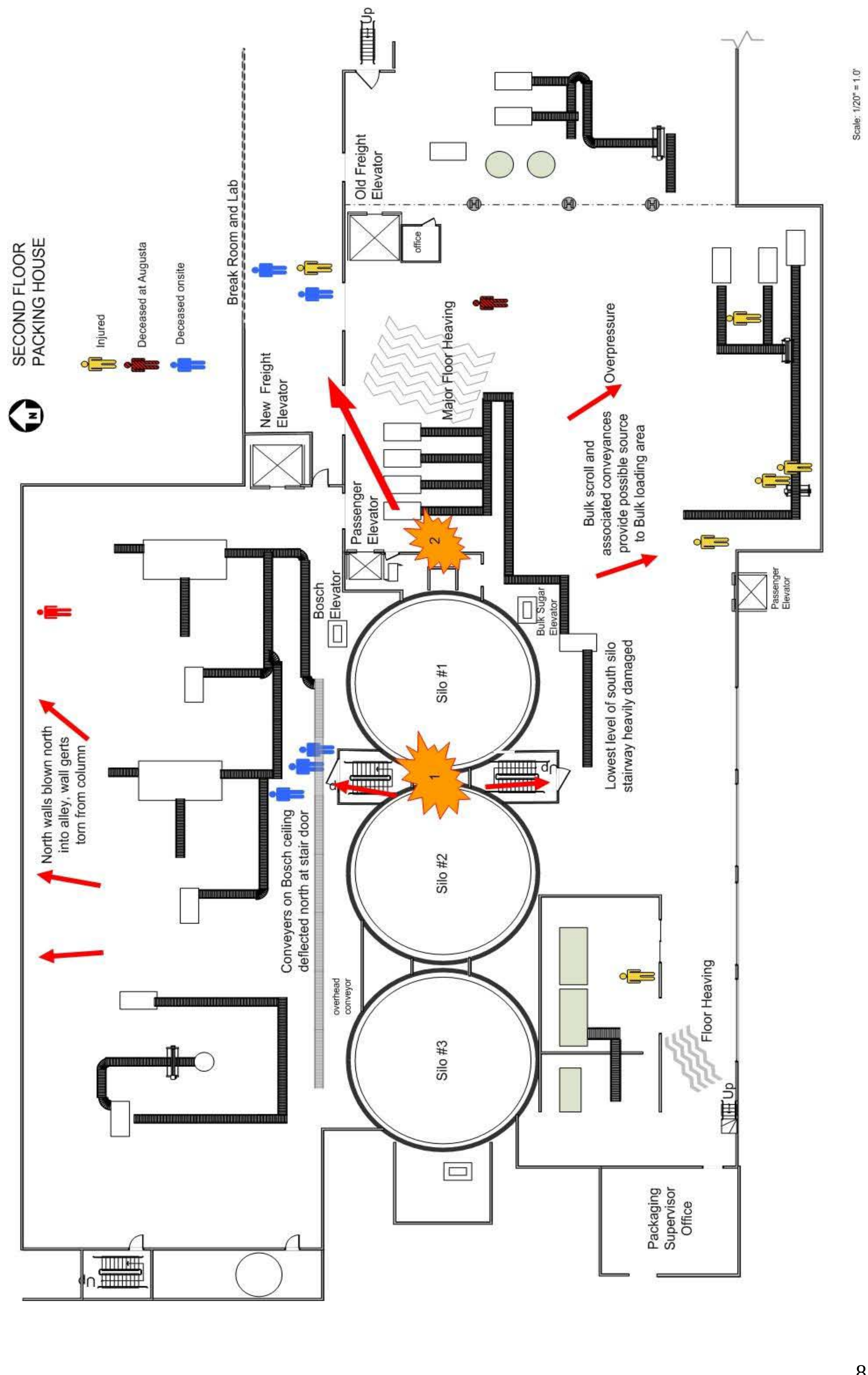

South Packing Building
A
Ign Seq
Secondary event
Pressure waves travel through scrolls to many tanks and hoppers in bulk sugar, J-bin, F Station
Secondary event
Sugar dust dislodged and intense fireballs travel through most areas. Sustained fires result in areas east and south of silo 2.
Minimum or no fire damage to the west of silo 2 on all five floors.
Sustained fires in bulk sugar, F station, char house roof.
Sustained fires in 2nd and 3rd floors granulator areas
B
Silos
Stairs first and second floor south side of silos 1-2 brick walls blown outward
Worker trapped between equipment and storage cabinet on 2nd floor south of silo 1. Fatally burned
South brick walls and windows blown out. Window glass and frames travel ~200 feet south. One embedded in insulation on liquid sugar storage tank
Packaging equipment dislodged/ into floor voids on second floor east of silo 1.
Employee trapped in void on 4th floor near south elevator. Fatally burned.
Employee fatally burned on 4th floor near the south elevator.
Large sections of 3" concrete floor areas heaved up on second, third, fourth floors.
Two employees seriously burned by fireball in south-east area 2nd floor.
Minimal fire damage to equipment in the area.
Three employees in south-west area 2nd floor burned, survive.
One employee on second floor near S elevator burned. Succumbed to burn injuries at burn center.
Brick walls on west side of packing building collapsed to the first floor and into palletizer room

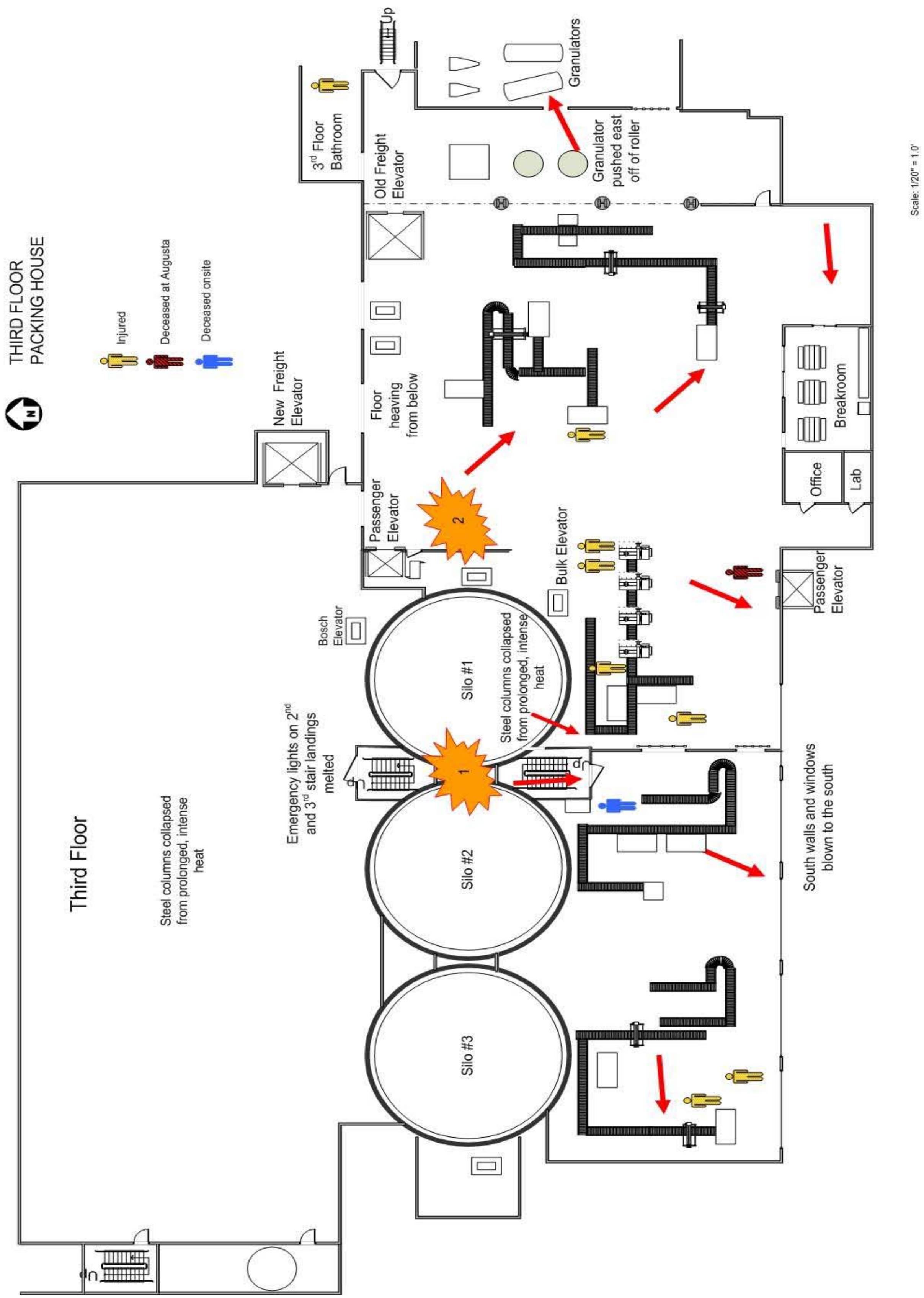

Lab / GO shop
Three workers in 2nd floor breakroom
A
Ign Seq
Secondary event
Sugar dust on 1st floor packing building horizontal surfaces lofted and ignited
Pressure wave and fire enters breakroom through floor and walls
Pressure wave and fire enters lab and shop areas
One worker escapes south into packing building
Two workers trapped in breakroom, fatally injured
Fire destroys structure

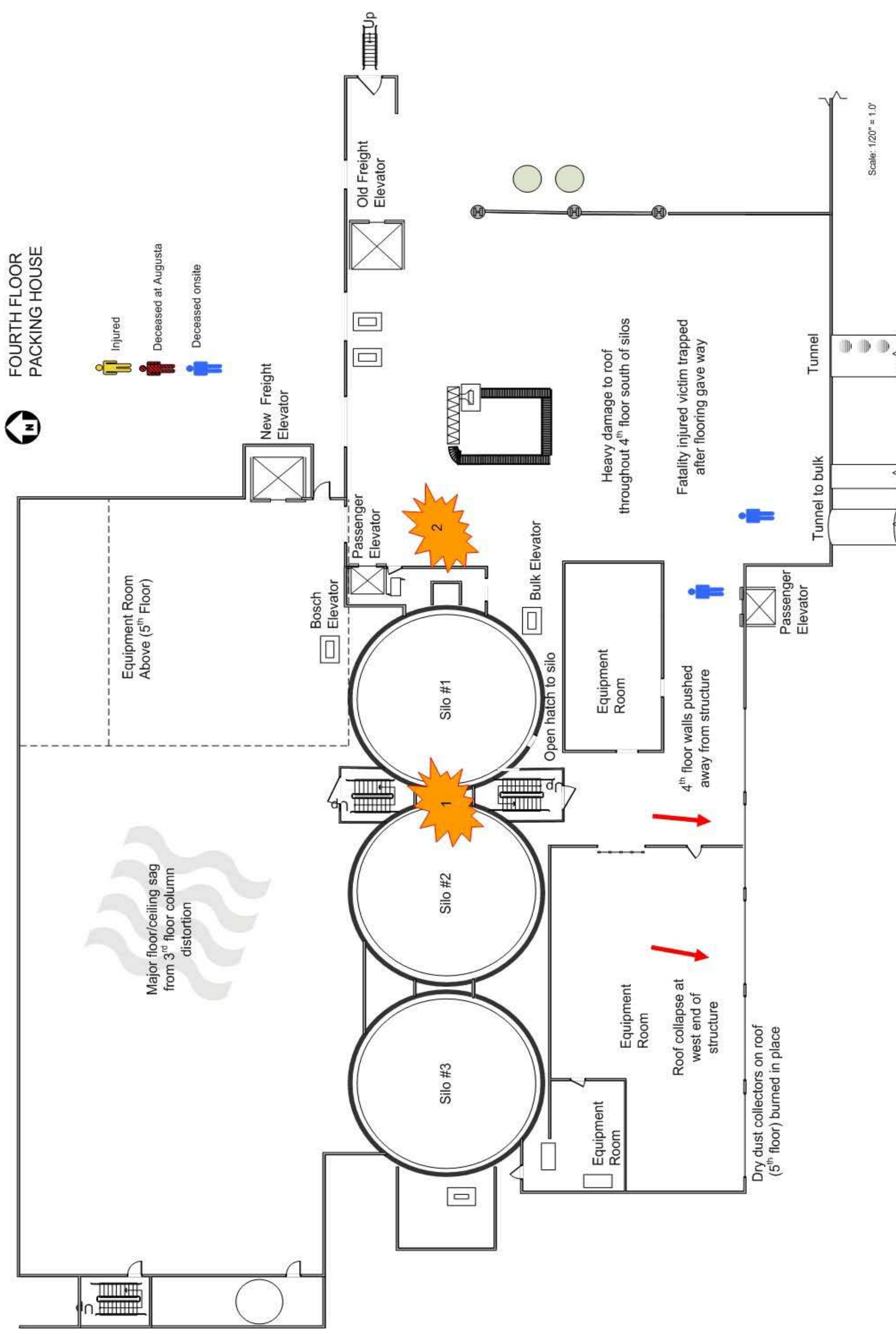
Appendix B – Explosion Progression in Packing Buildings



FIRST FLOOR
PACKING HOUSE
Injured
Deceased at Augusta
Deceased onsite
Equipment Room
Shop Office
Old Freight Elevator
Packaging Equipment
New Freight Elevator
Passenger Elevator
Manlift
Steel belt conveyor covers
Event #2
Production bucket elevator
Bosch Elevator
Bulk Sugar Elevator
Vac
Substation
Silo Operator Office
Event #1
Doors for Silos 2 & 3 show signs of pressure event from inside "pantlegs"
North walls blown north into alley, wall gerts torn from column. Damage worsens from west to east direction.
Blast patterns in westward direction on belt
Steel Belt
Silo 2 door
Silo 3 hatch cover
Passenger Elevator
Equipment Room
Electric Panels
Office
Storeroom
Office
E&I
Storeroom
Aerobelt
West Elevator
To Palletizing
Electrical Panels
Palletizer Office
Panels on west elevator tower blown out up to 5th floor
Flames observed by Packing House personnel
Roll-up door from west elevator


SECOND FLOOR
PACKING HOUSE
Injured
Deceased at Augusta
Deceased onsite
Break Room and Lab
New Freight Elevator
Old Freight Elevator
office
Up
Passenger Elevator
Bosch Elevator
Major Floor Heaving
Overpressure
Bulk scroll and associated conveyances provide possible source to Bulk loading area
2
Bulk Sugar Elevator
Passenger Elevator
Silo #1
1
Silo #2
Silo #3
Lowest level of south silo stairway heavily damaged
North walls blown north into alley, wall gerts torn from column
Conveyers on Bosch ceiling deflected north at stair door
overhead conveyor
Floor Heaving
Packaging Supervisor Office
Scale: 1/20" = 1.0'


THIRD FLOOR
PACKING HOUSE
Injured
Deceased at Augusta
Deceased onsite
Third Floor
Steel columns collapsed from prolonged, intense heat
New Freight Elevator
3rd Floor Bathroom
Up
Granulators
Old Freight Elevator
Granulator pushed east off of roller
Floor heaving from below
Passenger Elevator
Breakroom
Office
Lab
Bulk Elevator
Bosch Elevator
Passenger Elevator
Silo #1
Steel columns collapsed from prolonged, intense heat
Emergency lights on 2nd and 3rd stair landings melted
Silo #2
Silo #3
South walls and windows blown to the south
Up
Scale: 1/20" = 1.0'



FOURTH FLOOR
PACKING HOUSE
Injured
Deceased at Augusta
Deceased onsite
New Freight Elevator
Old Freight Elevator
Up
Passenger Elevator
Bosch Elevator
Bulk Elevator
Equipment Room Above (5th Floor)
Silo #1
Silo #2
Silo #3
Open hatch to silo
Equipment Room
Heavy damage to roof throughout 4th floor south of silos
Fatality injured victim trapped after flooring gave way
Tunnel
Tunnel to bulk
Passenger Elevator
4th floor walls pushed away from structure
Major floor/ceiling sag from 3rd floor column distortion
Equipment Room
Roof collapse at west end of structure
Equipment Room
Dry dust collectors on roof (5th floor) burned in place
Scale: 1/20" = 1.0'
1
2